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THE CONSTRUCTION, OPERATION, AND USE OF THE NORTH FORK INFILTROMETER

By P. B. Rowe, Associate Silviculturist
California Forest and Range Experiment Station
Forest Service

UNITED STATES DEPARTMENT OF AGRICULTURE

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Soil Conservation Service
U. S. Department of Agriculture
Washington, D. C.

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THE CONSTRUCTION, OPERATION, AND USE OF THE NORTH FORK INFILTROMETER ¹

By P. B. ROWE, *Associate Silviculturist*

California Forest and Range Experiment Station, Forest Service ²

INTRODUCTION

A knowledge of the infiltration capacities of the soils comprising a watershed is of real value in the formulation or application of any management program concerned with either flood and erosion control or the production of usable water. The infiltration capacities of soils have proved to be reliable indices of surface run-off and erosion hazards and valuable guides in determining methods of control. Infiltration data are also employed in several of the more recently developed methods of hydrograph analysis. The general use of infiltration data in watershed management has, however, been limited by the lack of adequate instrumentation and of practical methods of obtaining rapid and accurate measurements of the infiltration capacities of soils.

This publication describes the construction, operation, and use of the North Fork infiltrometer, an instrument developed primarily for determining the infiltration capacities of soils on large areas by sampling methods. Intensive laboratory tests of the infiltrometer and the infiltration studies in which it has been employed since it was first developed in 1934 indicate that it affords a practical and reliable means of measuring the infiltration capacity of soils under natural field conditions. In addition, it has proved particularly useful in determining the influence on infiltration of such factors as difference in types of vegetation cover, land-use practices, and cultural treatments.

These conclusions are further substantiated by infiltration studies made at the watercycle and soil experimental installations at North Fork, Calif., where the infiltrometer was first used. In the North Fork studies, test runs were made to check the infiltration-capacity measurements obtained through the use of the infiltrometer against those obtained from 1/40-acre surface run-off and erosion plots under natural

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²Grateful acknowledgment is extended to the many persons who have through their interest, advice, or actual assistance contributed to the developing and perfecting of the North Fork infiltrometer and the field procedures for its use. In particular, acknowledgment is due to G. W. Musgrave, Soil Conservation Service; to C. Kenneth Pearce and Richard A. Hertzler, U. S. Forest Service; and to the other members of the Subcommittee on Infiltration Measurements for Flood Control Surveys, U. S. Department of Agriculture, for their helpful suggestions and constructive criticisms; to Theodore W. Daniel, California Forest and Range Experiment Station, for assistance in perfecting and testing the instrument in the later stages of its development; to A. A. Hasel, California Forest and Range Experiment Station, for advice on statistical procedures; and to Morris Fram, U. S. Forest Service, and E. A. Colman, Henry W. Anderson, Karl J. Bermel, and Michael Flaherty, California Forest and Range Experiment Station, for suggestions regarding the design of the instrument.

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conditions of rainfall, in order to determine the feasibility of infiltration sampling as a means of extending the results of the plot and lysimeter experiments to other areas. The infiltrometer was also employed to isolate and determine the influence on infiltration of such factors as vegetation cover, soil moisture, soil freezing, slope, and intensity of rainfall, in order to obtain information for use in the interpretation and evaluation of the run-off data from the permanent plot and lysimeter installations. The results of these studies showed that the infiltration-capacity measurements obtained through use of the infiltrometer were, for practical purposes, identical with those obtained from the larger plots under normal conditions of rainfall, and that the influence of many of the factors affecting infiltration could be accurately, rapidly, and economically determined by infiltration sampling.

DESCRIPTION OF THE INFILTROMETER

A review of previous work on infiltration disclosed many highly desirable or essential features that should be included in any instrument to be used for infiltration sampling. In the development of the North Fork infiltrometer an attempt was made to incorporate as many of these features as practicable, considering the use for which the instrument was intended.

The infiltrometer has wide adaptability to sampling needs. It is sufficiently portable to permit random and comparatively rapid sampling and can be installed with very little disturbance of the soil. It provides for a comparatively even distribution of simulated rainfall at intensities of from $\frac{3}{4}$ inch to more than 10 inches per hour. The equipment is easily available and low in cost, and the operating procedures are reasonably simple. In addition, the instrument provides for unrestricted surface run-off, for wetting a border strip completely around the plot, for controlling wind effects, and for delimiting a constant horizontal area on any slope between 0 and 100 percent.

The infiltrometer also provides for a relatively high degree of precision in the measurements of amounts and intensities of rainfall and run-off, which permits determinations of such factors as total infiltration, infiltration capacity, surface run-off, depression storage, and surface detention. The operating procedure for the instrument provides for eliminating or controlling such factors as interception and evaporation losses in order that they will not complicate the infiltration determinations. The influence of interception, vegetation, litter cover, land use, soil moisture, and similar factors may, however, be measured with the infiltrometer by the use of special sampling technique.

An installation diagram for the infiltrometer is shown in figure 1, and in figures 2 and 3 the infiltrometer is shown set up and ready for a field run. As indicated in these figures the infiltrometer consists of several separate units of equipment, as follows:

1. Plot equipment for delimiting sampling units, complete with two side walls, end cut-off walls, brass spacer rods, and a run-off collector trough and cover.
2. Rain pan to be hung over the plot during calibration runs in order to obtain measurements of rainfall.

3. Rainfall and run-off collector tank equipped with stilling baffle, windbreaker cover, and point-gage support.
4. Point gage for obtaining rapid and accurate measurements of rainfall and run-off.
5. Hand-pressure pump outfit for maintaining a constant water supply to the sprinkler system during runs.
6. Sprinkler head equipped with support stakes and four fog nozzles for simulating rainfall.
7. Pressure-line assembly equipped with a sensitive 0- to 15-pound pressure gage, a precision pressure reducer, and two petcocks.
8. Windbreaker frame or tent support, capable of being rapidly assembled and dismantled.
9. Tent for use in eliminating wind effects during infiltration runs.
10. Canvas covers for use in preventing the wetting of the border areas of the plots during calibration runs and for covering the plots in order to minimize evaporation losses between runs.
11. Fifty-gallon drum or some similar type of container suitable for transporting water to the field installations and 25 to 50 feet of garden hose.
12. Miscellaneous items, such as Abney level with percentage scale, grass shears for clipping vegetation, 4-inch trowel or knife for installing plot sides, and other tools such as shovels, hammers, wrenches, screwdrivers, and pliers needed in assembling and installing the equipment.

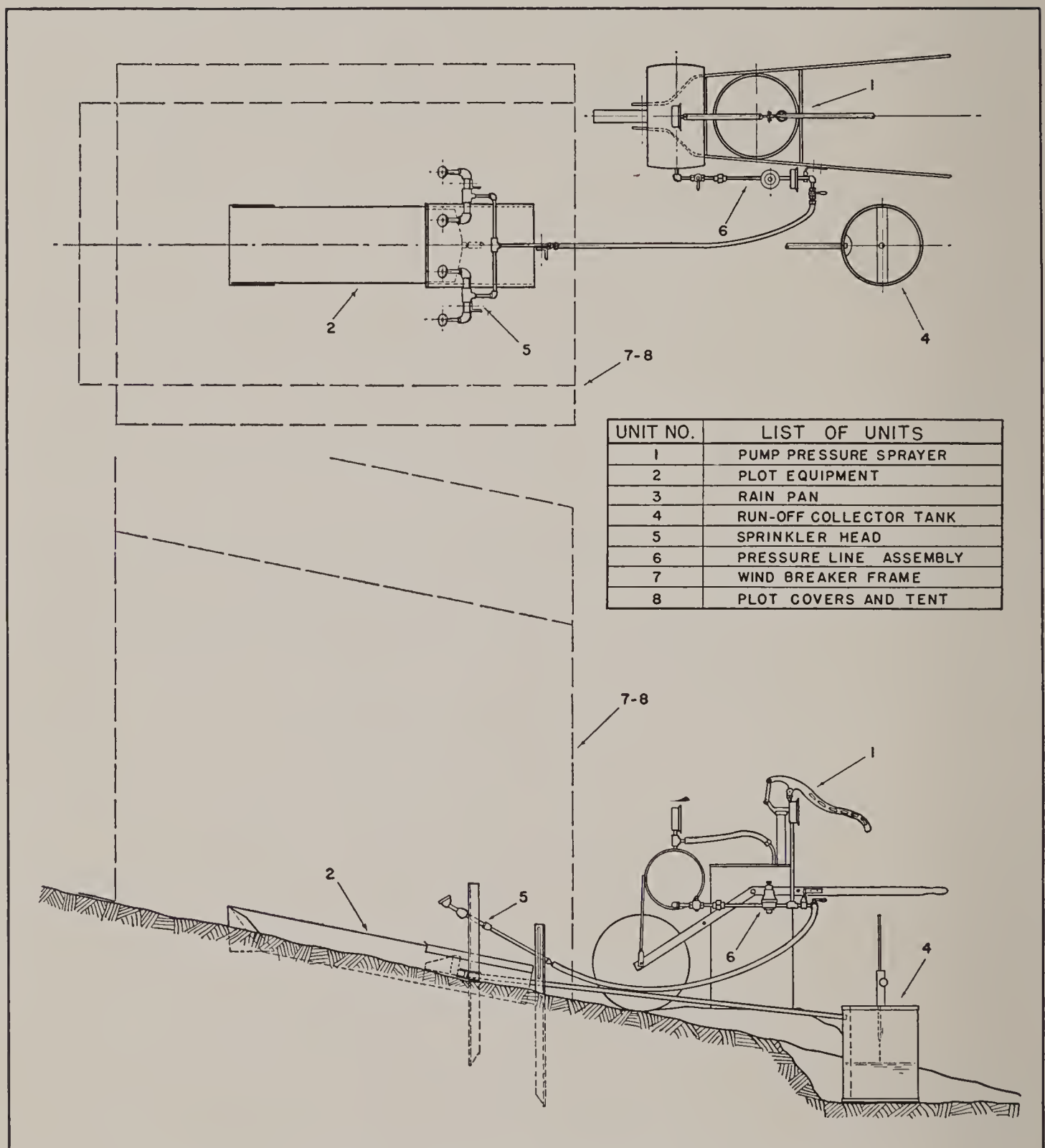


FIGURE 1.—Installation diagram for the North Fork infiltrometer.

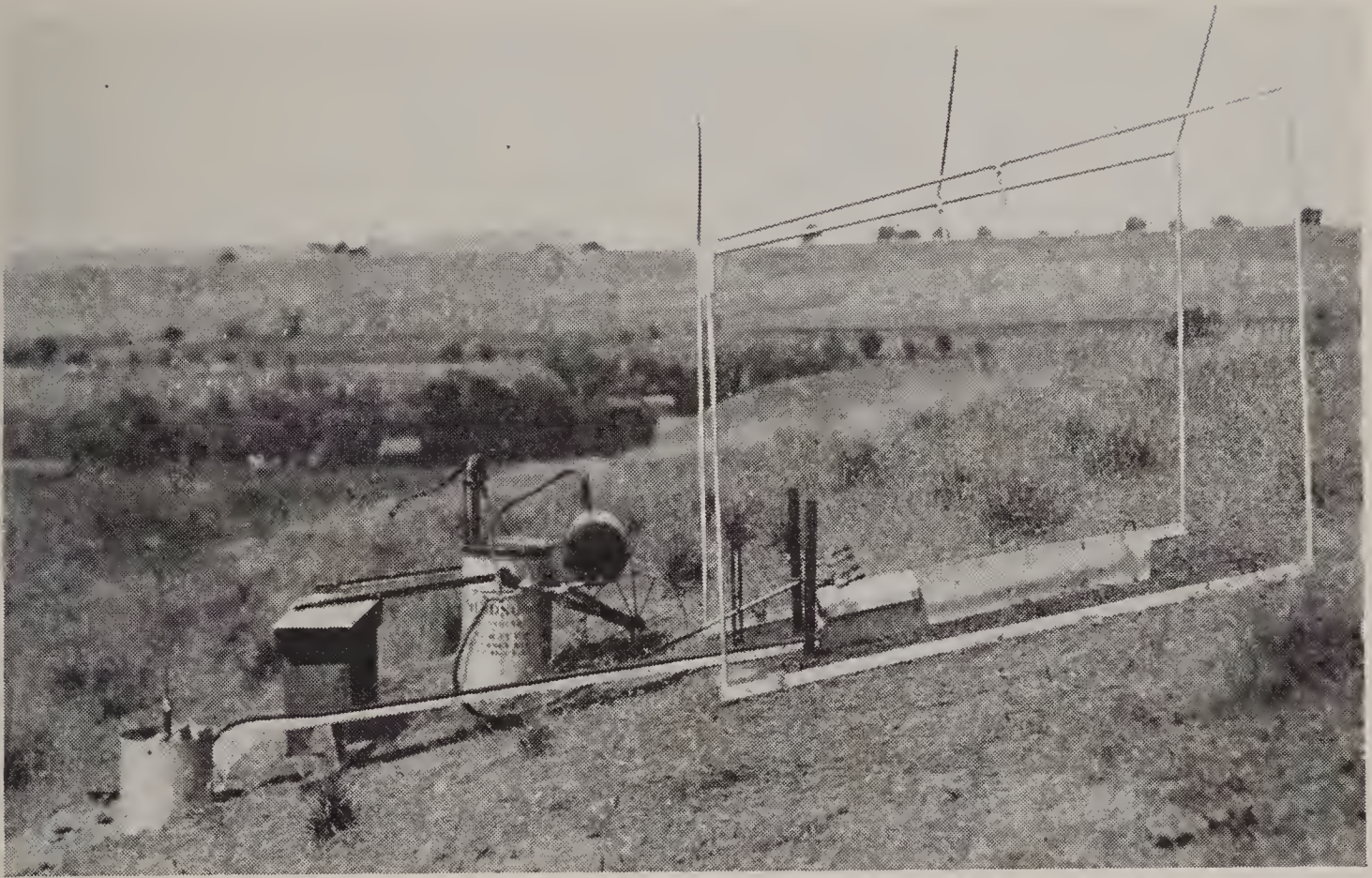


FIGURE 2.—The infiltrometer set up and ready for an infiltration run, except for the placing of the canvas windbreaker cover.

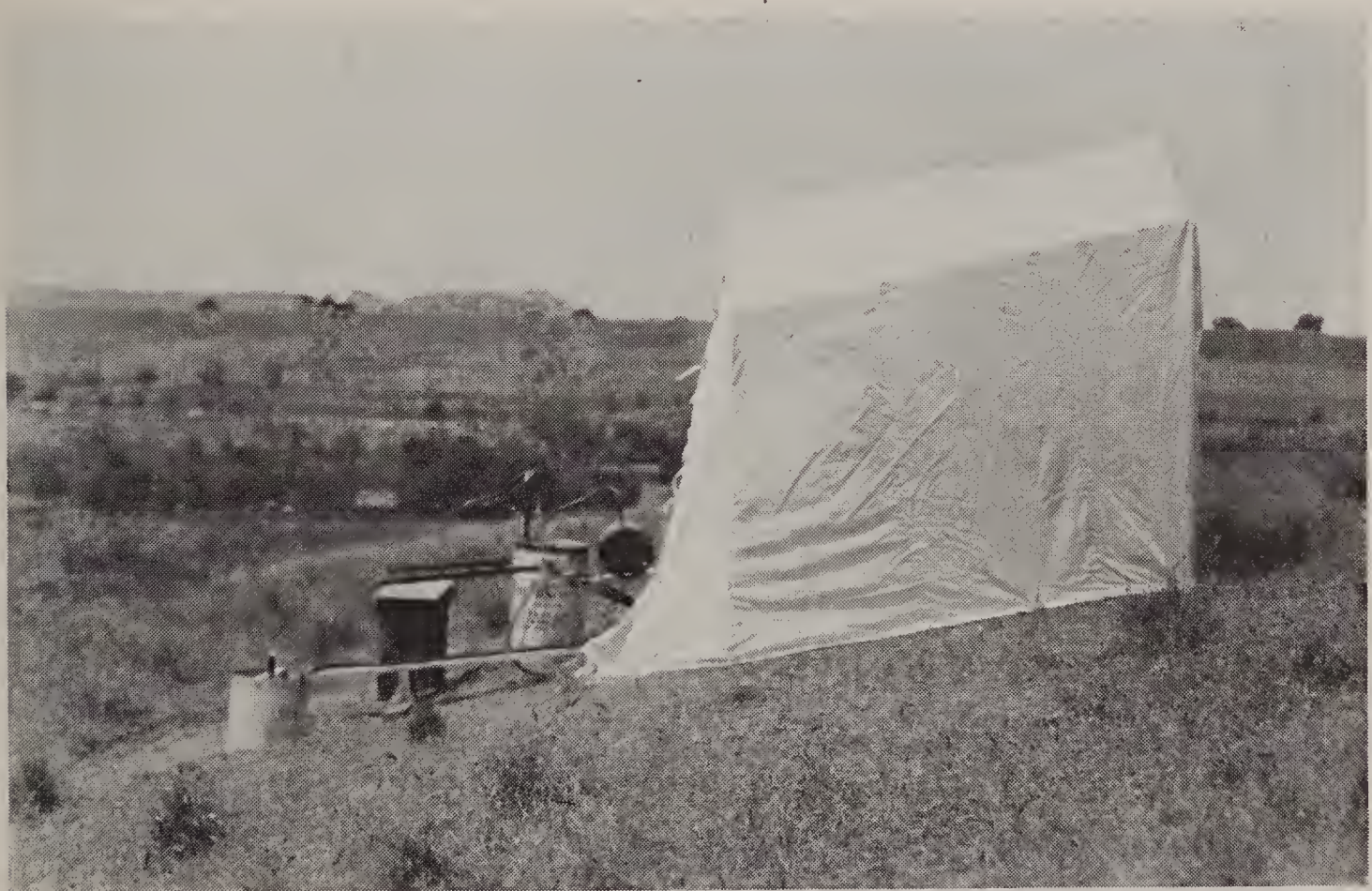


FIGURE 3.—The infiltrometer completely set up with the windbreaker cover in place.

The infiltrometer equipment is comprised partly of standard commercial apparatus that can be readily purchased in the open market and partly of equipment requiring special fabrication. Most of the latter type of equipment is of simple construction and can easily be made at any good sheet-metal shop. Although its construction requires no unusual skill, a high degree of precision is essential. Detailed descriptions, drawings, and specifications of the various units comprising the infiltrometer are included in the appendix.

The cost of the infiltrometer, including the equipment for one plot and accessories, as built in Oakland, Calif., in 1939, was approximately \$125. Efficient operation in most studies, however, will require at least three extra plots, three additional sets of support stakes, and three extra canvases for covering the plots between runs. This additional equipment will increase the cost of the infiltrometer about \$50, bringing the total cost to about \$175.

SAMPLING PROCEDURES

At the present time it appears to be impracticable to attempt to set up or propose a standard sampling procedure for general use in infiltration studies. Available infiltration data and the existing knowledge of the soil-water relations and other factors affecting infiltration are not sufficient to serve as a reliable basis for the formulation of a standard procedure. Differences in the soils, topography, vegetation, climate, land use, accessibility, and the water problems of the various areas sampled may often necessitate the use of different sampling technique. Differences in the purpose of various infiltration studies and the time, facilities, and technical personnel available for the work will also, on many projects, impose definite limitations both on the intensity of sampling and on the procedure employed. There are, however, certain prerequisites to all infiltration studies and certain basic principles that will in general apply to nearly all infiltration sampling.

The successful execution of an infiltration study or survey will largely depend upon the adequacy of sampling and will require an understanding of infiltration and of the factors influencing it. In general, the sampling will involve: (1) the delimiting of homogeneous infiltration areas or strata within the sampling universe³ according to expected infiltration capacities in order that the number of infiltration samples will be held to a minimum; (2) the selection of plots or sampling units within each sampling stratum so as to insure the best possible sampling; (3) the selection of plots for sampling special conditions, such as the influences of litter, herbaceous vegetation, soil freezing, and cultivation; (4) the determination of sampling error.

³Sampling universe as used in this publication refers to the area within which an infiltration study or survey is being conducted. Each sampling universe is comprised of one or more strata or areas of homogeneous infiltration characteristics.

SEGREGATION OF THE SAMPLING STRATA

The infiltration capacities of soils are governed to a large extent by the number and size of the water passageways they contain. These in turn are dependent upon such factors as structure and texture; organic and moisture content; number and size of root channels; insect, worm, and animal tunnels; topography; vegetation cover; and land use. Recognizable differences in these factors, particularly differences in soil structure, texture, and composition; in vegetation cover; and in land use are therefore useful in distinguishing and mapping sampling strata of expected homogeneous infiltration characteristics.

A preliminary reconnaissance of the sampling universe will ordinarily be advisable if not actually essential in mapping the infiltration strata. To simplify the work of the preliminary survey and to avoid any unnecessary duplications of effort full use should be made of all existing maps and available information concerning the soils, land use, vegetation, and other factors influencing infiltration. Soil technicians, foresters, engineers, and other professional workers having experience in the region of the study may often be the source of much valuable information and should be freely consulted relative to the problems with which they are familiar.

The number of sampling strata and the degree of refinement to be employed in segregating strata will, in general, be dependent upon: (1) the specific objective of the study; (2) the recognizable differences in the conditions expected to influence the average infiltration capacities of the areas comprising the sampling universe; (3) the precision desired in determining the mean infiltration capacities of the sampling strata; (4) the intensity of sampling that can be obtained under the particular restrictions imposed upon the study, such as the amount of time, technical assistance, labor, and equipment available for the work.

For example, if the objective of the study is to measure the influence of land use on the infiltration capacity of a soil, the mapping of the sampling strata will be very different from the mapping that would be necessary if the objective were to determine the mean infiltration capacity of a watershed for purposes of estimating flood hazards or for use in analysis of hydrographs. In the first instance, the sampling strata would be delimited on the basis of differences in land use or treatment. In the second instance, the sole criterion in mapping the sampling strata would be uniformity in expected infiltration capacities.

In mapping the sampling strata on the basis of recognizable differences in expected infiltration capacities it would be rather difficult and probably not a material improvement in the accuracy of sampling to attempt to segregate the sampling strata beyond the point of easily discernible and accurately determinable differences in the expected infiltration capacities. The sampling stratum need not, however, be continuous. Thus where land use, vegetation, and the other factors used in delimiting the infiltration strata form a patchwork effect, the areas of homogeneous infiltration characteristics can be grouped regardless of their position within the sampling universe. The total area of each stratum must, however, be known.

The degree to which the sampling universe is subdivided into strata will be governed to a large extent by the purpose of the study, the accuracy of obtainable precipitation records, and other data used in the interpretation and application of the results, together with the economic restriction imposed upon the work. Thus if only a rough estimate of the infiltration capacity is desired, if only relatively poor and inaccurate precipitation data are obtainable, or if the available time and money for the work permit only limited sampling, a high degree of refinement in the segregation of the infiltration strata may not be justified.

In the segregation of the sampling strata it should be recognized that when time is a limiting factor it is better to obtain adequate information on the more critical or important strata of a sampling universe than to obtain only a smattering of information on all the strata. For example, if the area of a possible stratum forms only a small proportion of the total area to be sampled, its relative importance as compared with the larger or more important strata may not justify its being mapped and sampled as a separate unit. Again, if several different strata have infiltration capacities well above the expected rainfall intensities of the region they may, for the purpose of many studies, be considered as a single stratum and sampled only to the degree necessary to establish the fact of their high infiltration capacities.

After an infiltration study has been completed the original mapping of the infiltration strata should be checked against the observed infiltration capacities, particularly if an action program is to be undertaken. If the inspection shows that various of the strata have more or less homogeneous infiltration characteristics, certain groupings may advantageously be effected. Conversely, if the inspection shows that other apparently homogeneous strata contain areas of unequal infiltration capacities, possibly demanding special or separate treatments, the segregation of these areas into additional strata or substrata may be advisable.

It is evident from the foregoing discussion that in delimiting sampling strata much will depend upon the purpose of the study and upon the region in which the work is conducted. Unique conditions will undoubtedly be encountered in nearly every study. Clearly, therefore, practicable and efficient segregation of the sampling strata will depend largely upon the knowledge, ability, and discretion of those responsible for the field work.

SELECTION OF SAMPLING SITES

After the various sampling strata are determined and drawn on a map, the selection of the individual sampling sites or plots is in order. The number and distribution of the sampling sites and the procedure employed in most studies will depend upon the available time and facilities for sampling and upon the degree of accuracy in sampling required to accomplish the purpose of the particular study involved.

The selection of sampling sites that will insure the best possible estimate of the infiltration capacities of the strata sampled under the limitations of a particular study will require considerable knowledge of sampling technique. Unless the field workers have had experience in sampling methods, it may save much time and expense to obtain the

assistance of a statistician in laying out and planning the sampling procedures.

In sampling a homogeneous infiltration stratum an attempt should be made, when practicable, to obtain a random or at least unbiased selection of the sampling sites in order to permit a valid estimate of error. In studies permitting only limited sampling or involving particularly difficult sampling conditions, random selection of the sampling sites may not be justified. In any event it must be remembered that the requirement of good sampling can best be met by distributing the samples as widely and as uniformly as possible.

The following procedure, which was employed in the random selection of sampling sites in an infiltration study recently completed, proved very satisfactory. The possible variation in the infiltration capacities of sampling sites within each sampling stratum was first estimated and used as a basis for calculating the number of samples that would be necessary to obtain a measure of the mean infiltration capacity to the degree of accuracy desired in the study. In order to insure a uniform distribution of the sampling sites each stratum as indicated on the map was then divided into blocks of equal area. The block divisions were made in a manner to insure maximum homogeneity within blocks in order that heterogeneity within the stratum, such as difference in slope, exposure, and cover would be reflected by variations in the infiltration capacities of the different blocks composing the stratum.

Two sampling sites were next chosen at random in each block. In making the random selection of the sampling sites each block was divided into 256 subdivisions of equal area. Each of the subdivisions was then given a number, and drawings were made to select the two subdivisions in each block to serve as sampling sites. The exact center of each of the subdivisions selected for sampling was accurately indicated on the base map used in locating the sampling sites in the field.

The actual sampling or plot sites were next located on the ground as near the position indicated on the map as possible under the conditions of the study. Where the plot sites included large exposed rock, large trees, recent soil disturbances, or other conditions not common to the sampling area as a whole, the plot sites were offset just far enough to avoid these particular conditions. Every precaution was taken to avoid personal bias in the selection of the plot sites. A systematic procedure was also followed to avoid bias where offsets in the sampling sites were necessary, such as the relocation of sampling sites at previously specified distances and directions from the site originally chosen.

Several modifications of the above procedure are possible. One modification that has proved useful in some studies consists simply of selecting in each stratum and drawing on the base map a given number (three or more) of equal-size sampling blocks covering only a part of the total area of the stratum, and confining sampling entirely to these blocks. In selecting the sampling plots within the blocks the same method, or one similar to that outlined in the preceding discussion, is followed.

The principal advantages of this modification are that it permits a more compact sampling, thus eliminating considerable travel time, and

that it offers a somewhat better opportunity to take advantage of established roads, trails, and other factors affecting accessibility and the cost of sampling. One of the disadvantages of the method is that a valid estimate of error is possible only for the areas actually sampled. If the blocks sampled, however, are well distributed and representative of the full range of conditions within each sampling stratum and if the analyses of the results do not indicate a significant difference in the variation between blocks as compared to the variation within blocks, the estimate of error would probably not be significantly different from that which would have been obtained if the sampling sites had been selected more at random.

A better distribution of sampling sites for any given number of samples can normally be expected from systematic than from purely random selection. If, therefore, only a limited number of samples or infiltration tests are obtainable it would be expected that the best estimate of the infiltration capacity of the sampling area would be obtained by a systematic selection of the sampling sites. It must be remembered, however, that any systematic selection of sampling sites, even though unbiased, will not permit a valid determination of the sampling error.

SAMPLING SPECIAL CONDITIONS

In many infiltration studies the sampling of special conditions to determine the possible effects of the various types of land use, vegetation cover, forest litter, soil freezing, seasonal variation in climate, soil moisture, and other similar factors, will be required. Such information will aid in analyzing and interpreting the results of all infiltration studies; will serve as the basis for predicting possible benefits of land treatments and for eliminating possible hazardous practices in watershed management; and hence will be of use in formulating action programs where the control of water is involved.

Whenever any of the factors listed above are of major importance in a study they should be sampled, if possible, as separate strata in the manner previously described. Otherwise, a few specially planned runs will be sufficient to isolate or determine the influence of any of these factors upon the infiltration capacities of the soils in the sampling strata. For example, the influence of such factors as forest litter on the infiltration capacity can be determined simply by comparing the results of runs made on a plot before and after the litter has been removed. A similar procedure can also be employed in measuring the effect of herbaceous vegetation, cultivation, interception, burning, and various other conditions. If the results of such tests are to be valid, however, special care should be taken to insure similarity in, and to control and regulate the influence of, all factors and conditions, other than the one being tested, that may affect infiltration.

One of the most important of the factors influencing infiltration, which in many studies will require special sampling technique, is soil moisture. For example, the infiltration capacity of a fine sandy loam, Sierra Nevada foothill soil, tested in California, was more than 10 times greater when air dry than when its moisture content was at field capacity. Thus the accuracy with which the influence of soil moisture is measured may to a large degree determine the usefulness of the infiltration data in estimating flood hazards and in the analyses of hydrographs.

The influence of soil moisture can best be measured by a series of runs made on certain selected plots. These runs should be started at field dryness and repeated at intervals of from 24 to 96 hours until the minimum infiltration capacities have been reached. The plots should be covered to prevent evaporation between runs, and a time interval long enough for the soil moisture to reach equilibrium and for complete soil swelling to take place should be allowed. Sufficient soil-moisture samples should be collected at the start of each run to permit an accurate determination of moisture percentage. A master curve can then be constructed, showing the influence of soil moisture on the infiltration capacity of the soil by plotting the observed infiltration capacities of the soil over the observed soil-moisture percentages. The soil-moisture content can, if preferred, be expressed as relative wetness.

The influence of soil saturation upon the infiltration capacity can be measured simply by continuing the field-capacity runs until absolute constant or minimum infiltration rates are reached. Recovery in the infiltration capacity of the soil upon drying can be observed by uncovering the plots after the wet runs have been completed in order to permit free evaporation and by making repeat runs after the desired time intervals have elapsed. Both the saturation and recovery tests will be useful in constructing the master infiltration soil-moisture curve.

Similar modification of the procedures described above can be employed in determining the effects of the various other conditions or factors influencing infiltration in any particular study. The responsibility for the exact procedure used in determining or measuring these influences will, for the most part, rest upon the field operators and will, therefore, require not only an understanding of the special problems involved but initiative and ability in solving the problems as they are encountered. It should be remembered, however, that in many studies the influence of certain of the factors and conditions affecting the infiltration capacities, such as slope, aspect, soil texture, and density of vegetation, may often best be determined through statistical analysis of the results and will, therefore, not require special sampling methods.

DETERMINATION OF SAMPLING ERROR

As has been indicated in the previous sections, it will often be desirable to make some simple statistical calculation in the field to determine whether a sufficient number of infiltration samples have been taken in a given sampling universe, stratum, or substratum to attain the accuracy desired in the measurement of the mean infiltration capacity. In making these calculations it should be remembered that various conditions, particularly soil moisture, may have a tremendous influence on the infiltration capacity. The calculation should, therefore, be based on samples for given specified conditions. For example, in the case of soil moisture, the calculation should preferably be based on infiltration tests made of soils with a moisture content at or near field capacity.

Once the mean infiltration capacity has been satisfactorily determined for a given set of conditions, the influence of changes in these conditions can be determined by special sampling, as previously discussed. It should be realized, however, that it will not ordinarily be possible to exclude all variations within the conditions sampled such, for example, as differences in exposure and degree of slope. These vari-

ations within the conditions sampled should, therefore, be carefully recorded so that their influence on infiltration can be determined by statistical analyses.

A statistical procedure that can be employed in determining sampling error is illustrated by the following example. The data used were collected during an infiltration study made on a 100-acre watershed near Friant, Calif., in cooperation with T. R. Smith, Office Engineer of the Bureau of Reclamation, United States Department of the Interior.

TABLE 1.—Infiltration capacities and their squares for 50 sampling sites of the Friant infiltration survey.

| Sample site | (x) Infiltration capacity <i>Inches per hour</i> | x ² | Sample site | (x) Infiltration capacity <i>Inches per hour</i> | x ² |
|----------------------------|--------------------------------------------------------|----------------|-------------|--------------------------------------------------------|----------------|
| 1 | 1.36 | 1.8496 | 26 | .45 | .2025 |
| 2 | 1.62 | 2.6244 | 27 | 1.89 | 3.5721 |
| 3 | .57 | .3249 | 28 | 1.20 | 1.4400 |
| 4 | 1.49 | 2.2201 | 29 | 1.20 | 1.4400 |
| 5 | .63 | .3969 | 30 | .73 | .5329 |
| 6 | .60 | .3600 | 31 | .86 | .7396 |
| 7 | 2.32 | 5.3824 | 32 | 2.12 | 4.4944 |
| 8 | 1.53 | 2.3409 | 33 | 1.82 | 3.3124 |
| 9 | 1.30 | 1.6900 | 34 | .63 | .3969 |
| 10 | 3.96 | 15.6816 | 35 | .38 | .1444 |
| 11 | .59 | .3481 | 36 | 1.48 | 2.1904 |
| 12 | .94 | .8836 | 37 | 2.58 | 6.6564 |
| 13 | .48 | .2304 | 38 | .74 | .5476 |
| 14 | 1.90 | 3.6100 | 39 | 1.25 | 1.5625 |
| 15 | .39 | .1521 | 40 | .97 | .9409 |
| 16 | 1.41 | 1.9881 | 41 | 1.47 | 2.1609 |
| 17 | 1.20 | 1.4400 | 42 | 1.14 | 1.2996 |
| 18 | .55 | .3025 | 43 | 1.17 | 1.3689 |
| 19 | 2.37 | 5.6169 | 44 | 1.14 | 1.2996 |
| 20 | 1.88 | 3.5344 | 45 | 2.38 | 5.6644 |
| 21 | 1.18 | 1.3924 | 46 | 2.78 | 7.7284 |
| 22 | 1.26 | 1.5876 | 47 | 1.52 | 2.3104 |
| 23 | .77 | .5929 | 48 | 2.07 | 4.2849 |
| 24 | 1.58 | 2.4964 | 49 | 1.60 | 2.5600 |
| 25 | .95 | .9025 | 50 | 1.96 | 3.8416 |
| Totals | | | | 68.36 | 118.6404 |
| Mean infiltration capacity | | | | 1.3672 | |

$$s. d. = \sqrt{\frac{S(x^2) - \frac{(Sx)^2}{n}}{n - 1}}$$

$$s. d. = \sqrt{\frac{118.6404 - \frac{93.4618}{49}}{49}} = \sqrt{\frac{25.1786}{49}} = \sqrt{0.5138} = 0.7168 \text{ in./hr.}$$

$$s. e. = \frac{s. d.}{\sqrt{n}} = \frac{0.7168}{7.071} = 0.10137 \text{ in./hr.}$$

- Symbols:
- x = Value for individual infiltration capacity determination
 - S = Summation
 - s. d. = Standard deviation
 - s. e. = Standard error
 - n = Number of observations

The standard error, in this case 0.101 inch per hour, is a measure of the adequacy of the sampling and the reliability of the mean infiltration capacity (1.37 inches per hour). Its value is such that if the mean were

again determined by repeated sampling of the same intensity the chances are 19 to 1 that the new mean would deviate less than twice the standard error from the previously determined mean. Thus a repeated sampling of 50 sites in this unit would provide a mean infiltration capacity of 1.37 inches per hour \pm 0.202 inch per hour in 19 out of 20 cases. The true mean infiltration capacity of the watershed can, therefore, be assumed to be within 14.8 percent of 1.37 inches per hour.

Suppose, however, that the requirements of the study called for the determination of the mean infiltration capacity to an accuracy within 10 percent of the true mean. The permissible standard error would then be:

$$\text{s. e.} = \frac{0.10 \times 1.37}{2} = 0.0685$$

The permissible standard error being known, the number of samples that would be required to obtain it can be calculated in the following manner:

$$\text{s. e.} = \frac{\text{s. d.}}{\sqrt{n}}$$

Whence:
$$n = \left(\frac{\text{s. d.}}{\text{s. e.}} \right)^2$$

Assuming the same standard deviation as before and substituting:

$$n = \left(\frac{0.7168}{0.0685} \right)^2 = (10.464)^2 = 109.5$$

Thus 109.5, or 60 additional samples, would be required to insure a determination of the mean infiltration capacity of the watershed within 10 percent of the true mean 19 times out of 20.

In setting up the accuracy requirement for an infiltration study, it should be borne in mind that a flat percentage tolerance in the determination of the mean infiltration capacities results in small means being estimated more closely than larger ones. A flat percentage tolerance, therefore, actually permits wide differences in the accuracy of the mean infiltration capacities of different strata when converted into actual volumes of water. For example, for a mean infiltration capacity of 0.10 inch per hour, a standard error of 10 per cent would in actual quantity of water involve only 0.01 inch per hour; whereas for a mean infiltration capacity of 5 inches per hour, a 10-percent error in the infiltration capacity would permit in actual quantity of water an error of 0.50 inch per hour.

Thus for a stratum with only 0.10 inch per hour infiltration capacity, not only would it be rather difficult to reduce the standard error to within 10 percent of the mean, but in addition there probably would be little need for such a high degree of precision because of the small quantity of water involved. In a stratum with a mean infiltration capacity of 5 inches per hour, however, not only would it be comparatively easy to attain a standard error within 10 percent (0.50 inch per hour) of the mean; but, because of the greater quantity of water involved, a higher degree of accuracy in estimating the mean would quite likely be required, particularly if the rainfall intensities of the region were equal to or exceeded the infiltration capacity.

An exception to the above rule can, however, be made for sampling strata in which the infiltration capacities exceed the highest expected rainfall intensities. In such strata, the accuracy of sampling need be only sufficient to establish the fact of an infiltration capacity significantly in excess of the highest expected rainfall intensities.

In the interpretation and application of infiltration data, the mean infiltration capacities of the various working units, strata, or substrata should be used with caution. For instance in the preceding example (p. 12) the area sampled, with its mean infiltration capacity of 1.37 inches per hour, appeared to be and was mapped as a homogeneous sampling stratum. On the basis of these results it might have been concluded that, under the conditions prevailing at the time of sampling, there would be little danger of surface run-off or floods unless the rainfall intensities exceeded 1.37 inches per hour.

When the infiltration capacities for the various sampling sites were spotted on the base map, however, it was at once evident that a large number of the sites having low infiltration capacities were included in a continuous group occupying about 34 percent of the sampling stratum adjacent to the main drainage. The medium infiltration capacities were included in another area comprising about 36 percent of the stratum, and a majority of the higher infiltration capacities were grouped in the remaining 30 percent of the area. The mean infiltration capacities for these areas were 0.83, 1.42, and 1.90 inches per hour, respectively, and their standard errors were 0.08, 0.12, and 0.21 inch per hour, respectively. Thus in this particular area, considerable run-off and erosion or even floods could occur from storms with rainfall intensities appreciably below the mean infiltration capacity of the sampling stratum as a whole.

Assuming that each test represented an equal proportion of the stratum and interpreting the results on the basis of individual tests, they show that for a rainfall of 0.5 inch per hour, surface run-off would occur over approximately 8 percent of the area. For rainfall intensities of 0.75, 1.00, 1.25, 1.50, 1.75, 2.00, and 3.00 inches per hour, surface run-off would occur over approximately 24, 34, 50, 64, 74, 84, and 98 percent of the area, respectively. Thus as the intensity of rainfall is increased from 0.5 inch per hour to 3.00 inches per hour, an increasingly greater proportion of the area contributes to surface run-off.

The proportion of total area contributing to the surface run-off from the watershed, however, is greatly influenced by the position within the stratum of the areas of low and high infiltration capacities. For example, if the areas of low infiltration were situated so that a part of the surface run-off from them flowed into areas of high infiltration capacities, much of the run-off might be absorbed by the latter areas. This added run-off into the areas of high infiltration capacities would in turn have an effect similar to that of increasing the rainfall intensities over these areas. Therefore, in the interpretation of the results of studies similar to the one described above, consideration should be given not only to the range in the infiltration-capacity measurements but also to the position of the areas of different infiltration capacities within each sampling stratum. When, however, the rainfall rates exceed the highest infiltration capacities within a unit, the mean infiltration capacity becomes operative and can be used in the prediction of surface run-off.

PROCEDURES FOR ASSEMBLING, INSTALLING, AND
OPERATING THE INFILTROMETER

After the sampling procedures have been decided upon and the sam-
pling sites selected, field sampling can be started. Before purchasing
and assembling the infiltrometer, the field party should be thoroughly
familiar with the specifications for the equipment and all phases of the
operating procedures.

ASSEMBLING AND TRANSPORTING EQUIPMENT

The infiltrometer should be set up and given a thorough test by the
field party before the field work is undertaken. Such a procedure will
serve as an excellent check on the equipment and will familiarize the
field party with its actual operation. Detailed drawings and the essen-
tial instructions for assembling and setting up the equipment are in-
cluded in the succeeding pages and in the appendix.

One of the most important features of the initial tests of the infil-
trometer will be to check the rainfall distribution and intensities for the
individual spray orifices and operating pressures. In assembling the
sprinkler head care should be taken to space the spray nozzles correctly.
After the nozzles are installed the alignment of the sprays should be
adjusted. This can be accomplished by removing the spray oscillators
and checking the trajectory and parallel alignment of the streams. Once
the sprays are adjusted all the movable joints of the sprinkler head, with
the exception of the nozzles, should be spot soldered and rechecked
against heat warping.

In setting up the sprinkler outfit and making the rainfall tests, the
directions included in the specifications (see appendix) and in the in-
structions for installing the spray equipment and for making infiltra-
tion runs should be followed exactly. It should be remembered that the
rainfall is always applied as fine drops just large enough to avoid dis-
turbances in delivery caused by air movements within the windbreaker.
The disk sizes, tank pressures, and line pressures found to be suitable
for obtaining the various rainfall intensities should be recorded in tab-
ular form for future field use, as indicated in table 2.

TABLE 2.—Spray orifices and gage pressures required for producing
given rainfall intensities.

| Rainfall rates | Disk orifice sizes | Approximate pressure | | Approximate posi- tion of sprinkler | | Approxi- mate angle of spray ¹ |
|------------------------|--------------------------|-------------------------------|-------------------------------|----------------------------------------|----------------|----------------------------------------------------|
| | | Tank gage | Line gage | Back of cover | Above cover | |
| <i>Inches per hour</i> | <i>Drill Number</i> | <i>Pounds per sq. in.</i> | <i>Pounds per sq. in.</i> | <i>Inches</i> | <i>Inches</i> | <i>Percent</i> |
| 1.00- 1.50 | 73 | 16-22 | 5-10 | 10-14 | 2-4 | 95-110 |
| 1.50- 2.00 | 68 | 15-20 | 4-8 | 8-12 | 2-5 | 95-110 |
| 2.00- 2.75 | 59 | 15-20 | 4-8 | 6-10 | 2-5 | 100-115 |
| 2.50- 3.50 | 55 | 15-20 | 4-8 | 6-10 | 2-5 | 100-115 |
| 3.25- 4.75 | 1/16 | 15-20 | 4-8 | 4-8 | 2-5 | 100-115 |
| 4.50- 7.00 | 49 | 15-20 | 4-8 | 4-8 | 2-5 | 105-120 |
| 6.00- 9.00 | 45 | 15-20 | 3-8 | 2-6 | 2-5 | 105-120 |
| 8.00-12.00 | 42 | 15-20 | 3-8 | 2-4 | 2-5 | 105-120 |

¹ Mean slope of the center line of the spray trajectory at the nozzle heads.

Another important item that will require attention during these initial tests is the calibration of the run-off collector tank. It will be noted that the specifications require the cross-sectional area of the collector tank to be just equal to or slightly larger than one-third the horizontal area of the plot. In the calibration of the tank, its cross-sectional area should be reduced to exactly 120 square inches, or one-third the horizontal area of the plot. This may be done by welding a steel rod or wire of the correct displacement size in a vertical position along the inside wall of the tank.

It would also be well at this stage of the work to develop a technique and to provide facilities for packing the equipment when it is in field use as shown in figure 4. Dustproof packing boxes or kits fitting into the bottom of the truck should be provided for the smaller and more easily damaged units, such as the gages, sprinkler heads, plot walls, collector tanks, and rain pans. Space should also be set aside for the pump outfit and for the water drums or containers which are described in the appendix under "Tools and accessories needed." The entire apparatus should be kept thoroughly clean at all times; and care should be taken to prevent denting or bending of the plot, rain pan, and collector tank walls; and to avoid possible damages to the sprinkler head, pressure gages, and other similar equipment when it is being moved or transported. If considerable use is to be made of the infiltrometer, a station wagon, or some similar type of covered truck, with space provided for the entire crew in addition to the water containers and infiltration equipment would undoubtedly prove the most satisfactory.

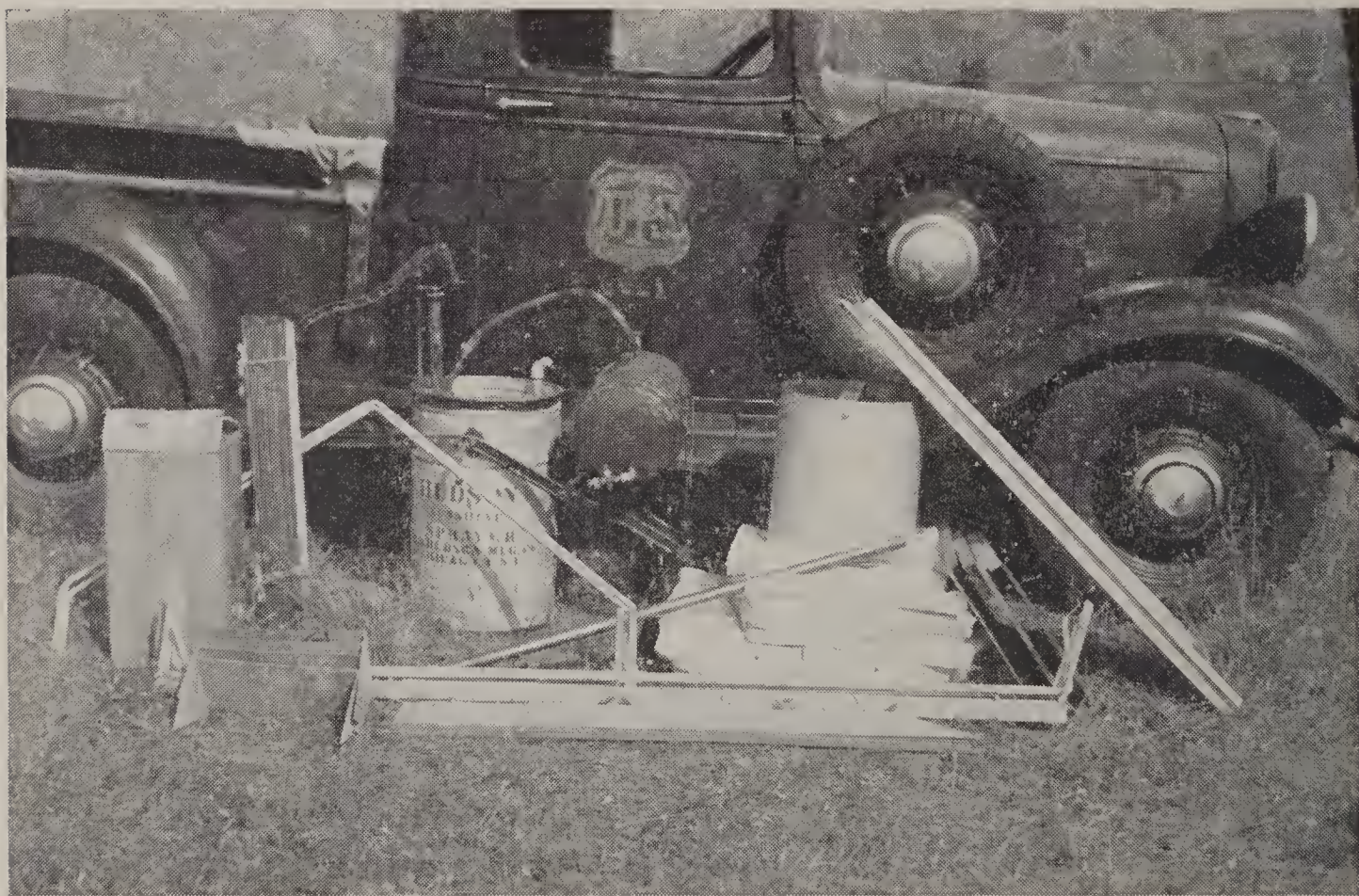


FIGURE 4.—The infiltrometer equipment ready for packing in a 1/2-ton truck.

INSTALLATION OF PLOT EQUIPMENT

Each infiltration outfit will, as a rule, include equipment for four or more plot units. A standardized method should be followed in the installation of the plot equipment, except as special or unusual conditions are encountered that may require slight changes in the procedure. In no event should modification in the installation technique be employed that would result in a departure from the basic principles on which the use of the infiltrometer is based.

Side and End Walls

The first step in actually installing the infiltration equipment is to place the plot in a position on the sampling site so that the sides are parallel to the direction of the steepest slope, as shown in figure 5. The sides are then sunk into the soil to a depth (at least $\frac{1}{2}$ inch at shallowest point) sufficient to prevent the inflow and outflow of surface run-off under the edges of the plot. When in final position, the rain-splitting edges of the side walls should be exactly 12 inches apart. The maintenance of the correct distance between the side walls is the function of the spacer rods, but an installation should always be checked for exact spacing before runs are started. An extra spacer rod can be used to test this distance.

The upper end wall is next installed. It should be placed in an upright or vertical position so that the top of the cutting edge is against and even with the top of the side walls. The 6-inch end wall should be used when the installations are made on flat or moderately flat slopes or where rocks, hardness of soil, or other obstacles are encountered that would involve difficulty in the use of the 7-inch walls. Extreme care should be exercised in installing the plot walls to avoid unnecessary disturbance of the soil surface, particularly on the inside of the plots.

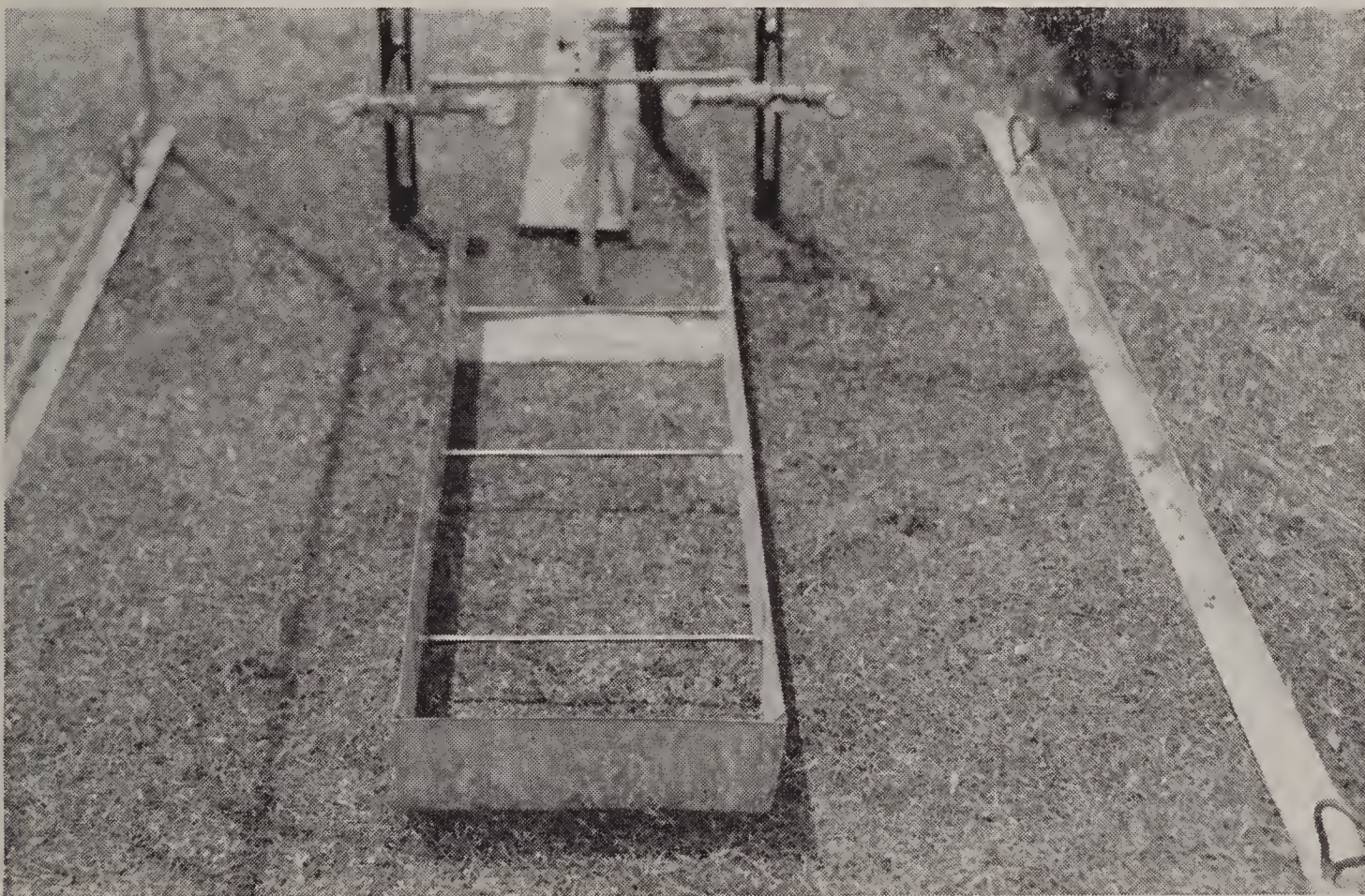


FIGURE 5.—Plot walls, run-off trough, and sprinkler head set in place on a 20-percent slope preparatory to an infiltration run

Before inserting the side and end walls it is best to remove all sticks, small surface stones, and other objects that may lie under the walls and prevent their placement without unnecessary disturbances of the soil. Using a butcher knife or a mason's sharp-edged trowel, two grooves should then be carefully cut in the soil along the outside edges of the plot walls, and both sides simultaneously forced into the soil until the desired depth has been reached. If there is not close contact between the plot walls and soil surface on the inside of the plots after the sides are installed, the space should be filled with soil carefully tamped in place with the trowel. It is also good practice always to tamp the soil firmly in place along the outside edge of the border walls to eliminate the possibility of surface water's entering the plot.

Run-off Trough and Cover

The run-off trough is next set in place between the side walls of the plot exactly 30 inches, horizontal measurement, from the back wall. In order to allow free and unrestricted entrance of surface run-off, the cut-off on the inside edge of the baffle trough should be placed in the soil to a depth sufficient to permit the spillway to be set slightly lower than the lowest level of the plot surface in immediate contact with the trough. The bottom of the trough should make close contact with the soil surface upon which it rests and should have not less than a $\frac{1}{2}$ -inch drop in its 5-inch length to assure rapid drainage of water. Once in place, the trough should be carefully inspected, and any side openings between it and the plot walls or along the inflow lip should be closed with clay or wet earth to prevent the leakage of surface run-off.

The cover should now be placed in position so that the upper or cutting edge is vertically over the inflow lip of the baffle trough and exactly 30 inches, horizontal measurement, from the inside top edge of the back wall. The placement of the run-off trough and cover can be expedited if the correct horizontal measurements for the various degrees of slope are inscribed on the plot and rain-pan walls, as shown in figure 18 of the appendix.

Run-off Collector Tank

The run-off collector tank can be installed in any convenient position below the plot if it is leveled to permit accurate measurement of water depth and connected with the drain pipe from the run-off trough in such a manner as to provide for the free flow of water from the trough to the tank. To facilitate the speed of draining and thus decrease instrument lag, the collector tank should be placed as close as possible to the lower edge of the plot and low enough to give the drain pipe a slope of not less than 10 percent. A distance of from 18 to 24 inches between plot and collector tank will, however, be necessary to allow the tank to clear the windbreaker tent and to prevent subsurface flow from the plot from filling the collector tank pit.

Spray Equipment

Before the spray equipment is set up it will be necessary to make an estimate of the infiltration capacity of the soil to be sampled in order to determine the proper size of spray orifices to be used during the run. Until sufficient experience with the soil and other conditions influencing infiltration has been acquired by the field crews in the particular area

in which the work is being done, the proper rainfall rates can best be determined by making trial runs near the plot installation. It must be remembered that the infiltration capacity of the soil is determined by measurement of the difference between rainfall and run-off rates. It is, therefore, evident that in order to measure the infiltration capacity, an excess of rainfall sufficient to produce surface run-off over the entire surface of the plot must be employed.

In order to be sure that the rainfall applied is in excess of the infiltration capacity of the soil over the full area of the plot, the rainfall rates should exceed the infiltration rates by at least 1 inch per hour for soils of low infiltration capacities and by 2 to 3 inches per hour for soils of high infiltration capacities. Employing rainfall intensities well in excess of the infiltration capacities serves also to decrease the length of time required for individual runs and to minimize the delay in run-off caused by depression storage and instrument lag. A table made up in accordance with the instructions on page 15 will serve as a guide in selecting the proper spray orifices and operating pressures and in determining the correct position of the sprinkler head to obtain the different rainfall intensities required by the individual runs.

After the proper spray orifices for use in connection with a run have been selected, two of the stakes equipped with adjustable supports for the spray apparatus are driven firmly into the ground on each side of the plot. The approximate position for placing these stakes is indicated in table 2. A third stake is next driven into the soil at the lower edge of the baffle cover, about 15 inches from the two side stakes and approximately 2 inches to one side of the center line of the plot. The sprinkler head is then placed in approximate position, as shown in figure 6, at a height of about 4 inches above the run-off trough cover, after which it is leveled, aligned, and tilted to the proper angle by adjustments of the supports.

A little experience will be required to judge the correct position of the supports, as it depends on the rain intensity used and the slope of the plot being tested. On steeper slopes it will be necessary to operate the spray farther forward and closer to the plot than on lower gradients. When low rainfall intensities are employed, other conditions being the same, the sprays, as indicated in table 2, will need to be operated farther from the plot and possibly at somewhat less tilt than for higher intensities.

Before the sprinkler head is set in place, it should be attached to the hose from the pressure-line assembly on the pumping outfit. Care should be taken to be sure that the pressure line is assembled and attached to the pump in accordance with the specifications in the appendix, figure 15.

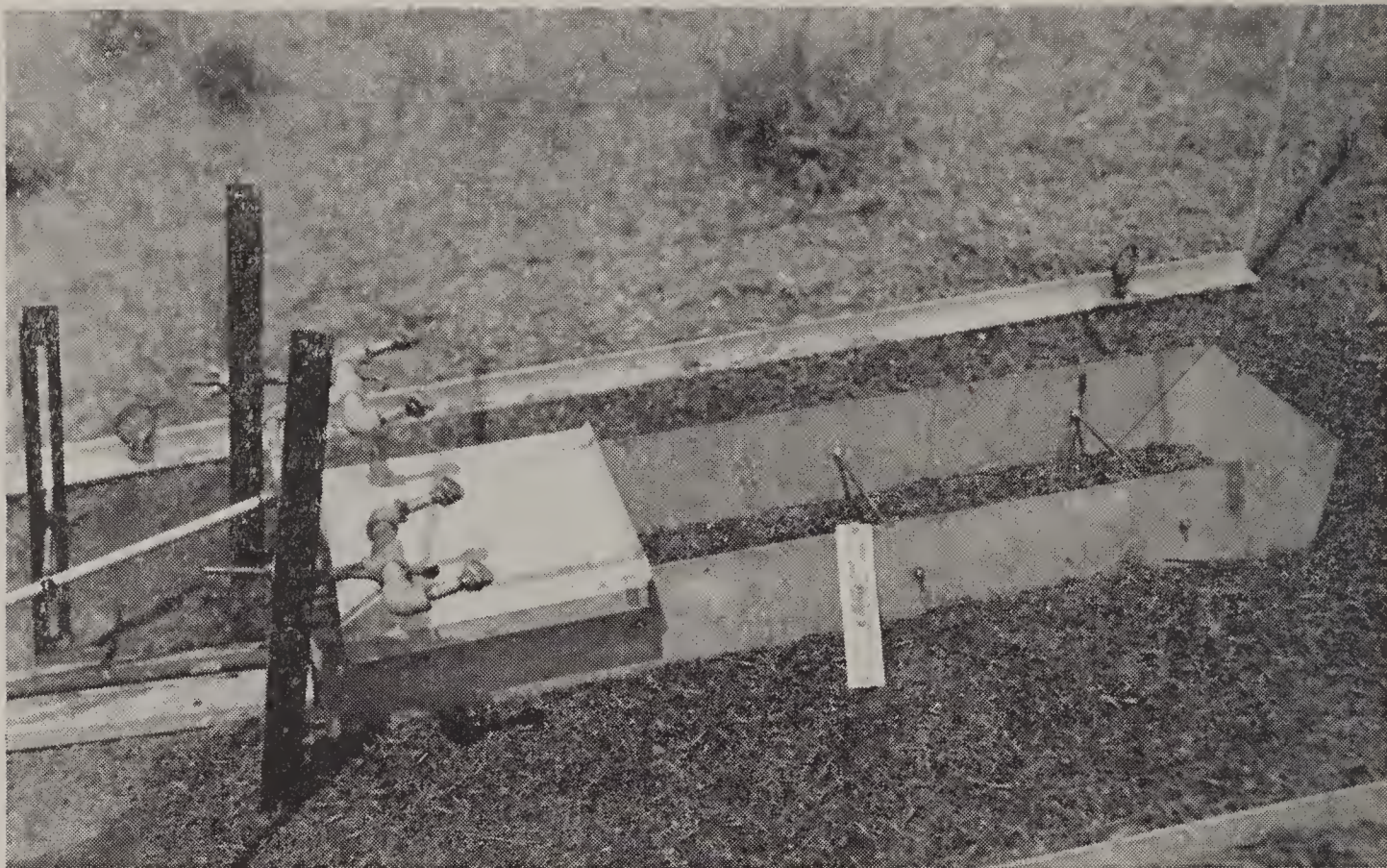


FIGURE 6.—Infiltrometer with plot walls, run-off trough and cover, support stakes, and sprinkler head in place ready for an infiltration run.

Windbreaker

Detailed instructions are not required for setting up the windbreaker, other than those included in the windbreaker and tent specifications, figures 16 and 17 in the appendix, as the equipment will not fit together except in correct position. Care should be taken, however, to set the sides parallel to and at an even distance from the sides of the plot.

The flaps at the front of the tent are constructed so that they can be extended over the sprinkling equipment when the plots are installed on steep slopes. On such installations the frame should be set far enough uphill to prevent the end wall hang-over from intercepting the spray intended for the plot surface. Before runs are made, care should be taken to stake down the sides and ends of the tent and to close the flaps so as to eliminate, insofar as possible, the billowing of the tent walls and other wind effects.

OPERATING PROCEDURES

The value of the infiltration data obtained from any study will be greatly influenced by the accuracy of the measurements and the circum-spection employed in the operating technique. In order to insure the maximum efficiency in the infiltration studies, the utmost care should be exercised by the field operators to maintain standard and systematic operating procedures.

Crew Organization

It is believed that in most studies a 3- or 4-man crew, consisting of a party chief of professional grade, an assistant party chief of professional or subprofessional grade, and one or two carefully selected laborers, will prove the most efficient.

The chief of the party should be responsible for preparing an operating schedule for the organization of the field work, for the location of exact sampling sites, and for the reliability and accuracy of the data collected. Whenever possible, the exact sampling sites should be located in advance of the actual initiation of the field sampling and, in any event, well in advance of the time the party is expected to make the infiltration test. This procedure will permit better planning and organization of the field work and will allow the chief of the party more time to supervise and assist in making the individual infiltration tests. After the field work has been completed the chief of the party should assist in the analysis and interpretation of the results obtained.

The assistant chief of the party should, in the absence of the chief, be responsible for the supervision of the field work and should at other times assist the chief of the party in the more technical phases of the field operations.

When only one laborer is provided he should do most of the pumping, assist with the installation of plot equipment, with water transportation, and in cases of emergency with the reading and recording of the field records. When two laborers are provided, the field work can, in most cases, be organized so that plot equipment can be installed and dismantled by the fourth member of the party. This will permit the operating crew to move directly from one plot to another and start runs without the delay of installing the equipment.

Where the sampling sites are readily accessible and not too widely separated, it may be possible to speed up the work considerably by providing two complete sets of infiltrometer sprinkling and measuring equipment. The extra equipment can then be set up with the sprinkler head, collector tank, rain pan, canvas plot cover, and windbreaker in place in advance of the arrival of the operating crew. If a technician is employed with the installing crew, or if one of its members is trained to test and adjust the sprinkling system, it will be possible in many instances for the installing crew to select the correct spray disks, to check and adjust the sprinkler head, and to have the plot equipment wetted and ready for a run upon the arrival of the operating crew. Upon its arrival the operating crew will turn over to the installing crew the sprinkling and measuring equipment used at the last sampling site for installation on the next plot to be sampled and will immediately take over the operation of the run. Such an organization of the work, in studies to which it is applicable, will greatly increase the number of runs that can be completed in a given time and should also decrease the total cost per run.

Preparation of Sampling Sites

After the infiltration site has been located and before the plot is installed, the aerial parts of the vegetation on the plot and border area should be carefully clipped to within $\frac{1}{8}$ to $\frac{1}{4}$ inch of the soil, as shown in figure 7. All other vegetal matter, such as litter, fallen branches, and twigs should also be carefully removed down to the mineral soil surface. This material should be removed by being carefully separated from the soil and lifted upward in such a manner as to avoid scraping or otherwise disturbing the soil surface. Where large vegetation is encountered, such as trees, the plots should be offset just far enough to exclude the

stems from the sampling area. Stems of any vegetation under 3 inches in diameter may be included in the plot area but should be cut off nearly level with the soil surface.

The purpose of removing the vegetation and vegetal debris from the plots is to eliminate the influence of interception during the infiltration runs in order to simplify the operating procedures and permit more accurate infiltration-capacity determinations. If the vegetation and litter cover is left in place it prevents the direct measurement of depression storage, increases the required length of runs by causing delay in obtaining constant run-off rates, increases evaporation losses, and by causing disturbances in run-off and in the application of rainfall increases the possibility of error in the infiltration measurements. Interception losses, which often amount to considerable proportions of total rainfall are, however, particularly important in determining total infiltration and should therefore be given special consideration in most infiltration studies.

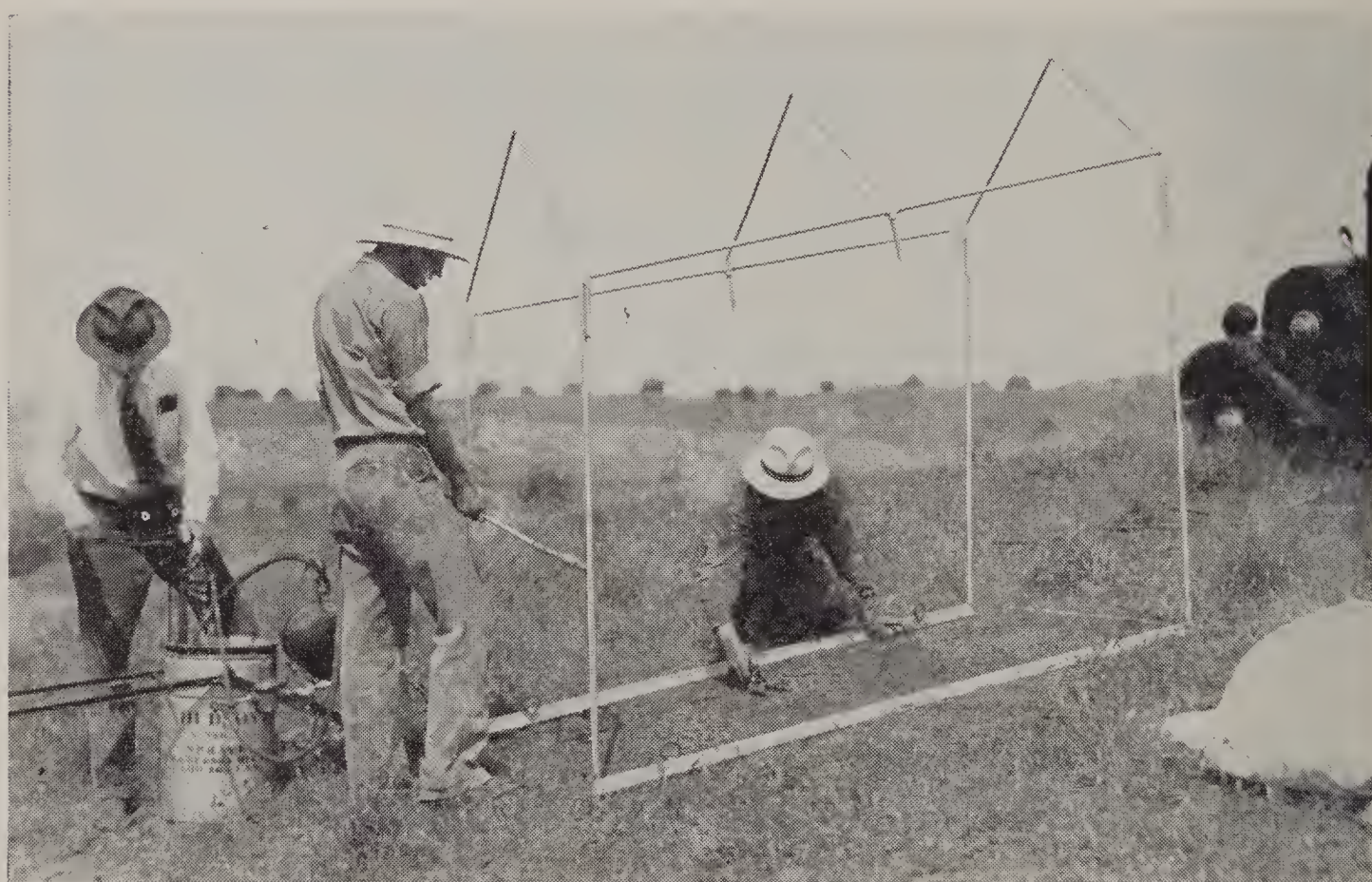


FIGURE 7.—Grass and herbaceous vegetation being removed from a sampling site in preparation for installation of the plot equipment.

Where runs are made for the purpose of determining the influence of vegetative cover, litter, or other factors described under "Sampling Special Conditions," (page 10) the vegetation or litter should not be removed until after the initial runs have been made. The results of these special infiltration tests should be used only in determining the influence of the special conditions sampled upon infiltration and should never be included in the infiltration measurements made to determine the mean infiltration capacity of the soil in a sampling stratum. Likewise where a significant portion of the surface area is occupied by rock outcroppings or by trees larger than 3 inches in diameter, the proportion of the sampling area thus affected should be estimated so that it can be taken into consideration in making infiltration predictions, but the areas thus af-

ected should not be included in the plots used for the regular infiltration-capacity measurements.

When the special runs are made without removing the litter or lower herbaceous vegetation, the litter and vegetation should be cut or separated along the plot boundary with a pair of sharp shears and the walls installed, as previously described. In these cases particular care should be taken to be sure that the plot walls extend well down into the mineral soil in such a manner as to prevent any possibility of either inflow or outflow of the run-off waters.

Soil Sampling

It will be desirable in all infiltration studies to obtain soil samples for the determination of soil moisture, moisture equivalent, volume weight, organic content, and other conditions that may be used in interpreting the results. The number and kind of samples collected should be consistent with the objective of the study and the available time and facilities for completing the analyses.

Soil-moisture sampling should be a requirement in all infiltration studies, as the interpretation of the results depends upon knowing the soil-moisture conditions existing at the time of sampling. The samples should be taken in duplicate before each infiltration run by a standard soil auger or sampling tube to a depth of from 12 to 18 inches. They should be collected by 3-inch increments down to the 6-inch depth and by 6-inch increments for greater soil depths. The soil-moisture samples, if large enough, can also be used for moisture equivalent and organic matter determinations, mechanical analyses, and other similar tests.

All samples should be collected from the border areas just outside the plot, and care should be taken to avoid all unnecessary soil disturbances. Each sample should be as nearly representative of the soil within the plot borders as possible and should be of sufficient volume, 100 to 200 grams air dry, to permit the analyses planned for the study under consideration.

Upon collection each sample should immediately be placed in a standard type of soil-sampling can, and the number of the can and the description of the sample recorded on the field form, as later described. If the covers of the sampling cans are not close fitting or if the samples are not to be weighed within 12 hours after collection, each can should be thoroughly sealed with one or two layers of friction tape to prevent evaporation. After the sampling has been completed, all the sampling holes should be thoroughly plugged and marked to avoid repeated sampling of the same spot.

Where infiltration runs are being made for only one soil-moisture condition (field capacity), only one sampling will be necessary for each sampling site. Infiltration runs and soil sampling for soil-moisture conditions at field capacity should never be undertaken until sufficient time has elapsed since the last application of water to permit the soil moisture to reach equilibrium. This will require a minimum of at least 24 hours for light sandy soils and may require as long as from 72 to 96 hours for heavy clay soils.

If volume weight, soil swelling, and total porosity determinations of

the soil in place are desired, additional sampling equipment will be required. As in soil-moisture sampling, standard methods should be followed in the collection of these samples. A tube-steel cylinder $1\frac{1}{2}$ inches in diameter, equipped with an adjustable depth control and sharpened at the bottom to permit easy entrance into the soil, is recommended for use in obtaining the volume weight and similar types of samples. In collecting the samples, care should be taken to obtain accurate depth measurements, and the area of the tube should be carefully calibrated to permit direct volume determinations.⁴

When volume-weight samples are collected, individual samples should be obtained by 1-inch increments for the 0- to 3-inch soil depth and by 2- to 3-inch increments for depths below 3 inches. In many studies, particularly in undeveloped soils, samples may not be required for other than the surface 0- to 1-inch depth. The volume-weight sample, as well as the samples for soil swelling and total porosity determination, should be taken at the same time the soil-moisture samples are collected. The same general procedure, except as otherwise indicated in the above discussion, should be employed in taking these samples as outlined for collecting the soil-moisture samples.

Standard methods should be used in the analyses of all soils collected in connection with the infiltration studies insofar as it is possible. Analyses for determining the influence on infiltration of variations in physical and chemical properties of soils other than those that have been listed may be highly desirable in many studies and are recommended wherever available time and laboratory facilities permit.

Making Infiltration Runs

After the plot installation has been checked for correct area and inspected for possible leaks and the soil samples have been collected, the rain pan should be hung in place over the sides of the plot, as shown in figure 8. The run-off trough cover should then be placed over the lower end of the pan in exactly the same position it is to occupy when in place on the plot during the infiltration runs. If a pan with unsealed end joints is used, these should be sealed with friction or cellulose tape.

The canvas border cover is next placed completely around the plot to prevent the wetting of the soil in the border strip before the actual infiltration runs are started. In all cases the buffer area around the plot and within the windbreaker should be treated exactly the same as the plot. To lessen the effect of walking on the border area, boards may be placed on the ground to serve as walks. A short test run should be made on each set-up to check the position of the sprinkler head for correct distribution of spray, to adjust the pressure regulators and spray nozzles, to wet the rain pan and the drain pipe, and to eliminate any leaks or obstructions to the free flow of water.

⁴Blue prints of volume-weight soil sampler designed and used with some success by the California Forest and Range Experiment Station can be obtained upon request.

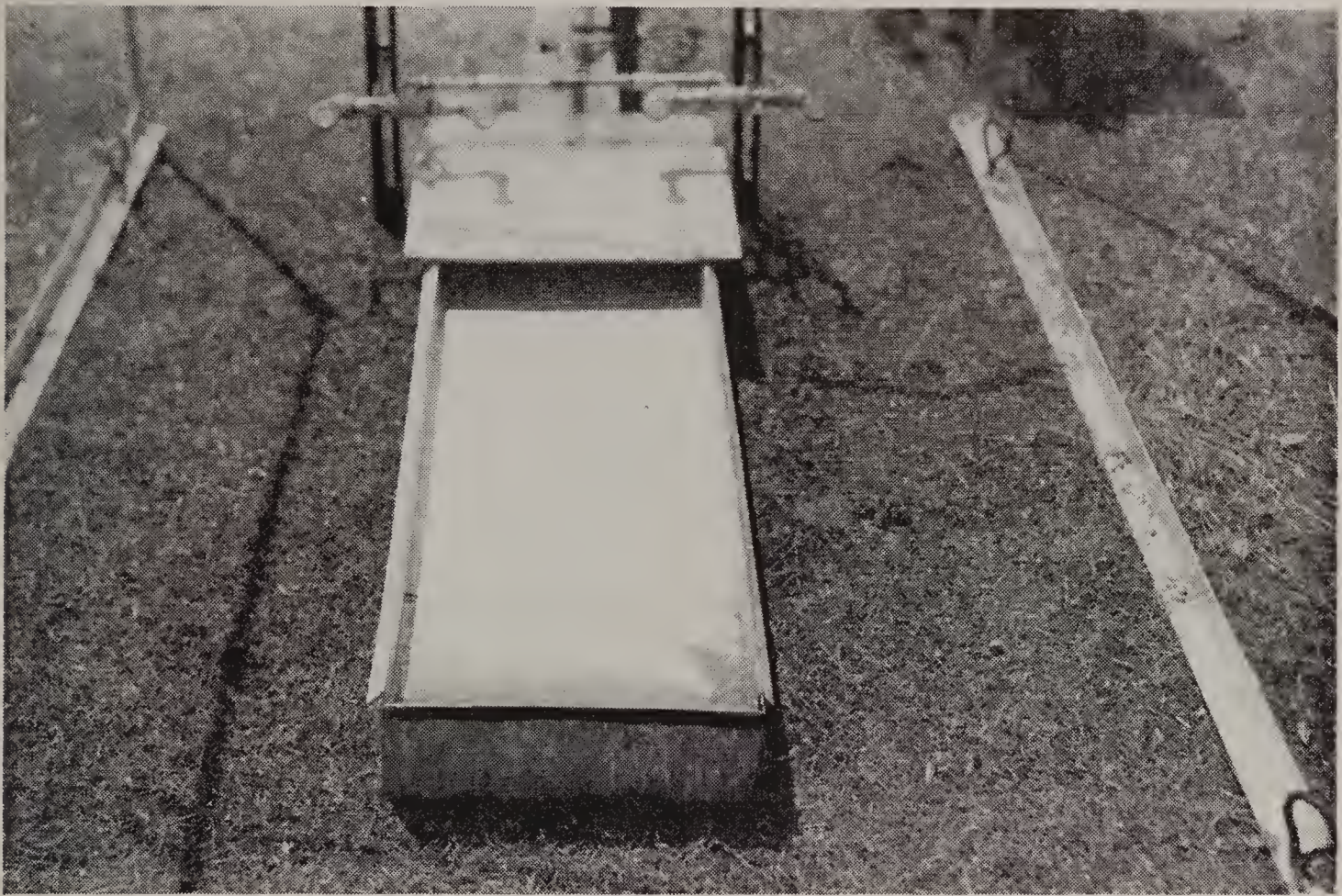


FIGURE 8.—Plot installation with run-off trough cover and rain pan in place for a calibration run.

In applying the rainfall, care should be taken to obtain as even distribution over the entire plot as possible. Perfect distribution, however, will seldom be accomplished; therefore the greatest concentration should be applied toward the upper end of the plot, because the surface run-off from this area will tend to compensate for a lower rainfall near the bottom of the plots. A check on the distribution of rainfall can be obtained by placing a weathered or darkened board under the spray over the full length of the plot for a period of time just sufficient to permit the formation of a rain pattern. A visual inspection of this pattern will give an excellent idea of the distribution.

As indicated under procedures for assembling and transporting equipment (p. 15), the pressures and nozzles should be regulated so that rainfall will be applied as fine drops just large enough to avoid disturbances in delivery caused by slight air movements within the windbreaker. The rainfall should never be applied as fog, because the air turbulence caused by the spray when the infiltrometer is in operation so greatly affects the distribution of mist that it is difficult to duplicate the runs accurately. After the spray equipment is properly adjusted, no changes should be made until the calibration and infiltration runs for the particular set-up have been completed.

In making runs, clear clean water should be used, and the pressure regulator and spray nozzles should be kept thoroughly clean. A lint-free cloth wrapped over a wire support around the pump intake has been found very effective in preventing clogging of the pressure lines and spray nozzles. Best results will be obtained in the application of rainfall by maintaining from 15 to 20 pounds pressure in the pressure tank and adjusting the regulator so as to give the desired pressure in the de-

livery line. The pressure in the delivery line as measured by the gage between the regulator and sprinkler head should be held constant during runs by regulating the speed in pumping. If the pumping is regular and continuous throughout a run, there should be little difficulty in maintaining the operating pressure within 1/10 pound of constant.

Two 5- or 10-minute calibration runs to measure the rate of sprinkling should be made in each infiltration run. The initial calibration run is made immediately before and the final calibration run immediately after the infiltration run. Exactly the same pressures and sprinkling set-up are employed in the two calibration runs as are used in the infiltration test. The rainfall rate employed must, therefore, be well in excess of the expected infiltration rate if valid measurements of the infiltration capacity of the soil are to be obtained. If the calibration runs do not check, it may be advisable to make one or more check runs to locate the cause of the trouble before proceeding further with the infiltration measurements.

Before the calibration runs are begun, the chief of party should be sure that all members of the crew, particularly the timers, are in readiness. The starting and ending time of the runs should be recorded to the nearest second, and the total duration calculated. The starting time of both the calibration and regular infiltration runs is taken at the exact instant (nearest 0.1 second) the petcock on the pressure-line assembly is opened, and the ending time corresponds to the exact instant of its closure. A stop watch will be very useful in making accurate time determinations and has the added advantage of permitting observation directly in cumulative or total elapsed time.

In the timing of the calibration runs there is an alternate method that can be used. This method consists of applying the rainfall with the rain pan in place for a short period until a constant flow of water into the collector tank is obtained. At a given time the discharge is stopped by means of a pinch valve on the rubber tubing at the collector-tank end of the discharge line. After the discharge is stopped the point gage is set and the discharge line is immediately opened. The gage reading is then taken and the starting time and the gage reading are recorded on the field form. At the end of the calibration run this procedure is again repeated, after which the rainfall is stopped and the final readings are taken and recorded. Although in theory this method appears more accurate than the first method described, field tests have not proved it to be so. This is in part due to the irregularities caused by the wave action in the flow from the rain pan, to errors in setting the point gage because of the time limitations, to loss in flow caused by the rain pan's running over before the point gage setting can be completed, and to errors in timing. Either method, however, will yield satisfactory results; but because of its simplicity, the first method is recommended for use until considerable experience in the operation of the infiltrometer has been obtained by the field crews.

The rate of rainfall is determined by converting into inches depth per hour the differences between the gage readings taken immediately before and at the end of complete drainage after the run, as described in the section, "Field Observations and Records" (p. 29). The calculation

of the rainfall rates will be greatly simplified if the runs are started and stopped at even-minute intervals.

After the initial calibration run has been completed, the rain pan and canvas border covers are removed, and the actual infiltration test is started. In the case of cultivated or very erodible soils the spacer rods should also be removed to prevent disturbances of the soil or erosion caused by the drip from the rods. The starting time of the run is taken at the exact instant that the petcock on the pressure-line assembly is opened and should be determined and recorded in exactly the same manner as in the calibration runs. In addition, the first appearance of water accumulation on the plot surface, the start of surface run-off or beginning of water movement into baffle trough, complete filling of surface depressions, and the start of drip into collector tank should be observed and accurately recorded. The occurrences of these phenomena can easily be observed through the peepholes in the back or at the sides of the tent and are particularly important in the analysis and interpretation of the results.

After run-off begins, gage readings are taken at regular time intervals. These readings can best be obtained by stopping the flow by means of a pinch valve on the rubber tubing at the collector end of the discharge line, just long enough (8 to 12 seconds) to permit an accurate setting of the point gage as described in the second method for timing the calibration runs. As soon as the gage is set the line is immediately opened, and the reading is taken and recorded. There will be some irregularities in the run-off readings because of wave action in the flow; but as no cumulative error occurs, these will be compensated for in the succeeding readings. The run-off readings should be taken at half-minute intervals or less until the run-off flow approaches a constant rate, after which the time between readings can be lengthened as desired.

Each infiltration run should be continued for a minimum period of at least 20 minutes after a constant rate of run-off has been definitely established. On dry soils this will require a longer time than on wet soils. After the constant rate of run-off has been maintained for the desired length of time the run is stopped by closing the petcock on the pressure line, and the exact time is recorded. At the end of the run, after the rainfall has been stopped, the run-off readings should again be taken at half-minute intervals, the readings being continued until run-off has ended.

The exact reading time of run-off or last movement of run-off water into the run-off trough and the final disappearance of water from the plot surface should be observed and recorded. It should be remembered that run-off often ends very shortly after rainfall ceases, thus requiring the observer to be in a position to observe its occurrence immediately after the rainfall has stopped. The last point gage readings for both the run-off and rainfall calibration runs are taken after the system has completely drained.

During a run observations should be made to determine whether sufficient rainfall is being applied to exceed the infiltration capacity of the soil over the entire area of the plot, to determine whether exces-

sive erosion is being produced because of too high rainfall intensity or too large raindrops, to guard against leaks, and to note and record any other factors that may influence the results or possibly invalidate the run. If the results of a run for some one of the above or various other reasons are not reliable, they should be discarded and another run made either on the same plot or on a different site, as the case may require.

Following the infiltration run, the rain pan and the canvas border cover are replaced, and the final calibration run is made. The duration of the run and the procedure followed should be exactly the same as in the initial run. After the run has been completed the average rate of rainfall for the two calibration runs is calculated and is used as a basis for determining the rate and volume of rainfall applied during the infiltration test. If the differences in the results of the two calibration runs exceed the desired accuracy, the data should be discarded, and the run should be repeated. When the calibration runs do not check within 2 percent or less, faulty technique, error in measurements, or improper functioning of the equipment is indicated.

If, after a run has been completed, additional runs are to be made on the sampling site, the plot and border areas should be covered to prevent evaporation. Wet burlap, wrung dry enough to prevent drip, placed over the plot and borders and covered with the canvas provided for that purpose has proved very effective in preventing evaporation from the soil surface between runs. Before starting the succeeding runs ample time should be allowed for the soil moisture to reach equilibrium and to permit normal soil swelling. The amount of time required for different soils to reach equilibrium after being wetted may vary greatly and should be independently determined by a special series of infiltration runs for each soil type. In all cases a minimum time of at least 24 hours should be allowed between the last run below field capacity and the field-capacity run.

One run should always be made on each plot after the moisture content of the soil has reached field capacity, since that is the soil-moisture condition normally prevailing at the time of floods. It is also the only soil-moisture condition that can be readily duplicated if repeated infiltration-capacity determinations are required. Before these field-capacity runs are made, enough water should be added by preceding infiltration runs, or by special wetting, to bring the moisture content of the soil to field capacity to a depth of at least 12 to 18 inches.

If runs are made to determine the influence of different rainfall intensities upon infiltration capacity, they should generally follow the infiltration runs that are made after the moisture content of the soil has reached field capacity. The same procedure should be employed in making these runs as in the regular infiltration runs. Sufficient time should be allowed between runs (24 to 96 hours) to permit the soil moisture to regain equilibrium; otherwise, the infiltration-capacity measurements obtained will be too low.

On many of the natural or undisturbed soils the infiltration capacity will be equal to or will exceed the highest expected rainfall intensities of the region. In such cases there is little point in making infiltration

runs employing higher intensities than will be required in making the initial infiltration-capacity measurements, for these will of necessity exceed the highest natural intensities.

Any differences observed in the infiltration capacity of a soil in the sampling of special conditions should be carefully checked to be sure that they are not due to factors other than those to which they are attributed, such as inadequate application of rainfall during the infiltration runs; run-off leaks into or out of the plot; moisture content of soil either below or above field capacity; changes in the physical properties of the soil, particularly porosity, because of puddling or erosion during the initial runs; and other similar conditions.

It should be remembered that the infiltration-capacity measurements desired in connection with most studies, other than those involving the sampling of special conditions, are the infiltration capacities of the soils of the sampling strata as they exist under natural conditions in the field. Care should be taken, therefore, to avoid any conditions, such as the disturbances of the soil during runs, that may in any way effect the normal infiltration capacity of the soils being sampled.

RECORDING AND INTERPRETING FIELD OBSERVATIONS AND RECORDS

In general, in the mapping of the sampling stratum and in the selection of the individual sampling sites, considerable information will be acquired concerning the sampling universe. This and any additional information relative to the area in which the infiltration study is being conducted should be made available to the field parties for their use in the interpretation of the field records and observations and in the preparation of their reports.

FIELD OBSERVATIONS AND RECORDS

Ordinarily two record forms will be used for each run, one for recording the field notes and observations and one for recording the instrument readings and calculations. Some field parties may, in addition, require standard cross-section sheets for use in plotting and inspecting the results of the infiltration data as they are accumulated. Samples of the field forms and procedures suggested for use in recording the field data and observations are included in the following discussions. The data shown on these forms were recorded during one of the field infiltration runs made in connection with the Friant infiltration studies.

Field Observations (Form A)

The field observation sheet (form CF&RES 563-A) is used for recording the physical conditions of the plot sampled, past and present land use, soil samples collected, and other general notes and observations pertinent to the run.

CF&RES 563-A

INFILTRATION STUDIES

Run No. 58-A

Rev.: 7-6-39

Date: 5-11-39

RI, 1-2

Location: Friant, Calif.

By TWD and HWA

Sheet 1 of 2 sheets

 SERIES Strat. I PLOT 21-2 run 58-A TIME 3:50 P DURATION 24 min. 46 sec.

PLOT CONDITION: Moderately grazed by sheep. Soil wetted to 12" 24 hours before run. Grass clipped to 1/4 inch stubble. Litter removed.

SOIL DESCRIPTION: TYPE: Lower Sierra foothill, reddish gray, fine sandy loam. ORIGIN: Residual soil. Parent rock biotite schist.

PHYSICAL CONDITIONS: Without crumb structure; slightly compacted by sheep grazing; crumbly when dry; low organic content.

PROFILE DESCRIPT.: A₀—Trace; A₁—Trace, gray; B—0-12", reddish gray, high mica content; C—Deeply weathered, biotite schist, strike N 55° W, 60° SW dip. Depth of soil 12".

FLORA AND FAUNA ACTIVITY: Grass and herbaceous roots to bedrock; few insect and worm holes.

DESCRIPTION OF SURFACE CONDITIONS: Slightly crusted; beginning of erosion pavement; no large depressions; no rock outcrop on plot; density of stubble 10%.

EVIDENCE OF EROSION: Moderate sheet erosion; no gullies.

SLOPE: 18%. EXPOSURE: North. POSITION OF SLOPE: Top, near ridge.

VEGETATION: TYPE: *Bromus* and *Festuca* grass type. DENSITY: 30%.

LITTER: TYPE: Dry *Erodium* sp. Av. DENSITY: 20% Av. DEPTH: 1/8".

LAND USE: PAST: Open grazing by sheep and cattle until 1934. Moderate grazing by sheep and cattle 1934-38. Burned over in September 1936.

PRESENT: Light seasonal grazing by sheep.

GENERAL NOTES AND OBSERVATIONS: Plot conditions as described above are fairly representative of area in immediate vicinity. Occasional small rock outcropping, less than 1% of area affected.

NOTES ON RUN: Gage reading during run fairly constant. Rainfall distribution good. Velocity of surface flow 18" per minute. No erosion. No leak or other irregularities.

Stop watch used for timing run.

SOIL-MOISTURE SAMPLES (Give sample can number, depth, and time taken.): Can #100, 0-3" depth; can #139, 3-6"; and can #153, 6-12". Hit rock at 12". Samples collected just prior to run.

OTHER SAMPLES (Indicate purpose and give complete information as above.): Volume weight samples, can #103, 0-1" depth, composite of 3 samples; soil moisture at about field capacity.

Run-off turbidity sample jar #108.

If additional space is needed for notes, drawing of soil profile, etc., use back of sheet.

As shown in the sample form, the file designation is placed in the upper left-hand corner, and the run number, date of run, initials of field observers, and the sheet number of the total number of sheets used for the run are recorded under the proper headings in the upper right-hand corner. The name of the study, nearest town and State, and any other data needed to place the sampling area are entered in the space after "Location."

In the block headed "SERIES" the stratum is indicated by number

or letter; under "PLOT" the plot number is entered as indicated on the base map; under "run" the number of the run is recorded as in the upper right-hand corner and whether it is the first, second, or third run on the plot is indicated by the letters A, B, C, etc., starting with A for the initial run. The "TIME" refers to the actual time the run was started, and "DURATION" to the length of run.

Under "PLOT CONDITION" is recorded any special treatment prior to the run, wetness of soil, and other similar conditions peculiar to the individual plot that may influence the results.

In the "SOIL DESCRIPTION" block, the name, color, and texture of the soil should be entered under "Type." The parent rock material and the source of the soil, as for example, residual or transported, is included under "Origin." A description of structure, mineralogical character, organic content, cohesiveness, compactness, and other physical properties of the soil that would influence its infiltration capacity should be recorded under "Physical conditions." The profile description ("Profile descrip.") should give the depth and include a brief description of each soil horizon. A drawing of the profile can be made on the back of the sheet, if desired. The record of the amount and depth of root penetration, and amount and distribution of animal and insect disturbances, such as angleworm burrowing and ant workings, should be entered under "Flora and fauna activity."

The "DESCRIPTION OF SURFACE CONDITIONS" should show amount of rock outcrop, proportion of area covered by stones, number and size of depressions, and other characteristics of the plot surface. "EVIDENCE OF EROSION" may be recorded as none, sheet, or gully, and the degree may be shown as very little, little, moderate, severe, and very severe. The "SLOPE" as measured along the sides of the plot is recorded in percentages. "EXPOSURE," or the direction in which the plot faces, is recorded as north, northwest, west, etc., as the case may be. The "POSITION ON SLOPE" is recorded as top, middle, or bottom to indicate the position of the plot with respect to the valley of the smallest drainage basin containing the plot.

In the block headed "VEGETATION: Type" the vegetation should be briefly but accurately described. For agricultural lands the crop is recorded. For pasture or range lands the type of grass and other herbaceous vegetation, brush or tree cover, and names of the predominating species in the order of their abundance are recorded. For forest areas the type should be given either as brush, hardwood, conifer, or mixed hardwood and conifer, followed by a list of predominating species in the order of their importance and their age class, as, for example, spruce-aspen, mixed conifer and hardwood type, 40- to 60-year age class. Where an understory of brush or herbaceous vegetation is encountered in the forest types a description of this cover should be included and the density of the cover indicated separately by crown classes.

The total density of the cover recorded under "Density" refers to the percentage of the soil within the plot that is covered or shaded by the vegetation. It may be determined by estimating the proportion of the soil surface that would be hidden from the view of an observer if

he were looking at the soil through the vegetation from an observation point situated directly above the plot. Where the vegetation is removed from the plot surface by cutting or clipping, an estimate of its density should be obtained before removal. The estimate of the stem or stubble density should be entered under the "DESCRIPTION OF SURFACE CONDITIONS."

In the block under "LITTER" the "Type" and "Density" are determined and recorded in much the same manner as the vegetation types. The average depth ("Av. depth") represents the average thickness of litter over the plot as a whole. This may, however, if preferred, be expressed as a range, as 1 to 2 inches. In forest and other vegetation types where the litter is composed of one or more layers, a description of each layer should be included and the depth specified. The layers can usually be differentiated as: L-layer, unaltered remains or detritus of plants and animals; F-layer, layer of partially decomposed organic matter in which the plant structures are still plainly visible; and H-layer, humus layer where decomposition has gone so far that the plant structures are no longer distinguishable.

Under "LAND USE:" "Past" and "Present," is recorded all the information that can be obtained relative to the use of the area. Local residents; soil, vegetation, geological, and land-office surveys; and the recorder's own personal observations are all good sources of information. The description of each plot should be as detailed and accurate as possible but does not need to duplicate information contained in reports on the sampling universe or sampling stratum.

The block under "GENERAL NOTES AND OBSERVATIONS" should be used for any additional description of the soil or other conditions that may, in the opinion of the observer, have a bearing on the infiltration results. Differences between existing conditions in the plot sampled and the general vicinity surrounding the plot, which might influence infiltration or be of value in the interpretation of the results, should also be described. In addition, a detailed account of the run, any irregularities in operation or instrumentation, and any other information pertinent to the run that may affect the results should be included.

A record of the soil and run-off samples collected should be entered in the blocks headed "SOIL-MOISTURE SAMPLES" and "OTHER SAMPLES" at the time the samples are taken, in accordance with the instructions given on the form. Standard laboratory forms designed for the particular analyses for which they are to be used will ordinarily be the most satisfactory for use in recording the results of the soil-moisture determinations and other laboratory analyses. After the laboratory work has been completed these forms can be attached, or the results of the analyses transferred to the infiltration field forms for ready reference.

In supplying the information requested in form A, emphasis should be placed on those factors and conditions most affecting infiltration. Some of the observations required (such as the description of soil profile) can be made to best advantage at the end of the last run on the sampling site, when the plot borders can be taken up and soil excavations made. Descriptions and information included in the report

on the sampling stratum or, when two or more runs are made on the same plot, the description or information included in the first report and pertaining equally well to conditions existing during succeeding runs need not be duplicated.

Field Records (Form B)

The field record sheets (forms CF&RES 563-B and -C) are used to record the actual observed data, as described in the instructions for "Making Infiltration Runs" (p. 24), and provide for the necessary office computations of rainfall, run-off, and infiltration. The headings down to "CALIBRATION RUNS" are exactly the same as those of form A and, therefore, need no explanation.

| CF&RES 563-B Rev. : 7-7-39 RI, 1-2 | INFILTRATION STUDIES Location : Friant, Calif. | Run No. 58-A Date : 5-11-39 By TWD and HWA Sheet 2 of 2 sheets | | | | | | | | | | | |
|-------------------------------------------------------------------------------------|-------------------------------------------------------|-------------------------------------------------------------------------|------|---------------|-----------|------|-----------|-------|------------------|---------|--------------|-------------|--------|
| SERIES Strat. I PLOT 21-2 run 58-A TIME 3:50 P DURATION 24 min. 46 sec. | | | | | | | | | | | | | |
| CALIBRATION RUNS : Rainfall, inches per hour, average of runs used 2.83. | | | | | | | | | | | | | |
| INITIAL RUN : Pressure tank gage, 15 lbs. Line gage, 4 lbs. Disk No. 56. | | | | | | | | | | | | | |
| Starting time, 0. Ending time, 5 min. Duration, 5 min. | | | | | | | | | | | | | |
| Gage rdg. : Before run, 4.60. After run, 5.305. Diff., 0.705. Inches per hr., 2.82. | | | | | | | | | | | | | |
| FINAL RUN : Pressure tank gage, 15.5 lbs. Line gage, 4 lbs. | | | | | | | | | | | | | |
| Starting time, 0. Ending time, 5 min. Duration, 5 min. | | | | | | | | | | | | | |
| Gage rdg. : Before run, 3.28. After run, 3.99. Diff., 0.71. Inches per hr., 2.84. | | | | | | | | | | | | | |
| RUN-OFF : (Ratio plot to tank area=3:1). (Rainfall: Ratio plot to tank area=3:1). | | | | | | | | | | | | | |
| Remarks | Reading time | | | Diff. Sec. | Mean time | | Gage rdg. | | Run-off in. dph. | | Cum. ppt. | Ppt-run-off | |
| | Hr. | Min. | Sec. | | Min. | Sec. | Cum. | Diff. | Cum. | Per Hr. | | Cum. | In/Hr. |
| Start run | | 0 | 0 | 0 | 0 | 0.0 | 0.90 | 0 | 0 | 0 | 0 | 0 | 0 |
| Start RO | | 3 | 40 | 220 | 1 | 50.0 | 0.90 | 0 | 0 | 0 | .1729 | .1729 | 2.8293 |
| | | 5 | 56 | 136 | 4 | 48.0 | 0.95 | .05 | .0167 | .4420 | .2798 | .2631 | 2.3876 |
| | | 6 | 33 | 37 | 6 | 14.5 | 1.00 | .05 | .0333 | 1.6152 | .3089 | .2756 | 1.2162 |
| | | 7 | 16 | 43 | 6 | 54.5 | 1.05 | .05 | .0500 | 1.3981 | .3427 | .2927 | 1.4316 |
| | | 7 | 56 | 40 | 7 | 36.0 | 1.10 | .05 | .0667 | 1.5030 | .3742 | .3075 | 1.3320 |
| | | 8 | 33 | 37 | 8 | 14.5 | 1.15 | .05 | .0833 | 1.6152 | .4033 | .3200 | 1.2162 |
| | | 9 | 10 | 37 | 8 | 51.5 | 1.20 | .05 | .1000 | 1.6249 | .4324 | .3324 | 1.2065 |
| (Indicate end of rainfall and run-off below.) | | 9 | 49 | 39 | 9 | 29.5 | 1.25 | .05 | .1167 | 1.5416 | .4630 | .3463 | 1.2831 |
| | | 10 | 24 | 35 | 10 | 06.5 | 1.30 | .05 | .1333 | 1.7075 | .4905 | .3572 | 1.1211 |
| | | 11 | 02 | 38 | 10 | 43.0 | 1.35 | .05 | .1500 | 1.5822 | .5204 | .3704 | 1.2505 |
| | | 11 | 38 | 36 | 11 | 20.0 | 1.40 | .05 | .1667 | 1.6700 | .5487 | .3820 | 1.1600 |
| | | 12 | 15 | 37 | 11 | 56.5 | 1.45 | .05 | .1833 | 1.6152 | .5778 | .3945 | 1.2162 |
| | | 12 | 50 | 35 | 12 | 32.5 | 1.50 | .05 | .2000 | 1.7178 | .6053 | .4053 | 1.1108 |
| | | 13 | 24 | 34 | 13 | 07.0 | 1.55 | .05 | .2167 | 1.7682 | .6320 | .4153 | 1.0588 |
| | | 14 | 03 | 39 | 13 | 43.5 | 1.60 | .05 | .2333 | 1.5323 | .6627 | .4294 | 1.3015 |
| | | 14 | 42 | 39 | 14 | 22.5 | 1.65 | .05 | .2500 | 1.5416 | .6933 | .4433 | 1.2831 |
| | | 15 | 13 | 31 | 14 | 57.5 | 1.70 | .05 | .2667 | 1.9394 | .7177 | .4510 | .8942 |
| | | 15 | 48 | 35 | 15 | 30.5 | 1.75 | .05 | .2833 | 1.7075 | .7452 | .4619 | 1.1211 |
| | | 16 | 21 | 33 | 16 | 04.5 | 1.80 | .05 | .3000 | 1.8218 | .7712 | .4712 | 1.0145 |
| | | 17 | 02 | 41 | 16 | 41.5 | 1.85 | .05 | .3167 | 1.4663 | .8034 | .4867 | 1.3610 |
| | | 17 | 33 | 31 | 17 | 17.5 | 1.90 | .05 | .3333 | 1.9278 | .8278 | .4945 | .9058 |
| | | 18 | 07 | 34 | 17 | 50.0 | 1.95 | .05 | .3500 | 1.7682 | .8545 | .5045 | 1.0588 |
| | | 18 | 44 | 37 | 18 | 25.5 | 2.00 | .05 | .3667 | 1.6249 | .8836 | .5169 | 1.2065 |
| | | 20 | 04 | 80 | 19 | 24.0 | 2.10 | .10 | .4000 | 1.4985 | .9464 | .5464 | 1.3275 |
| | | 21 | 14 | 70 | 20 | 39.0 | 2.20 | .10 | .4333 | 1.7126 | 1.0015 | .5682 | 1.1211 |
| | | 22 | 23 | 69 | 21 | 48.5 | 2.30 | .10 | .4667 | 1.7425 | 1.0557 | .5890 | 1.0852 |
| | | 23 | 34 | 71 | 22 | 58.5 | 2.40 | .10 | .5000 | 1.6883 | 1.1116 | .6116 | 1.1459 |
| End of run | | 24 | 46 | 72 | 24 | 10.0 | 2.50 | .10 | .5333 | 1.6650 | 1.1682 | .6349 | 1.1650 |
| RO stopped | | 26 | 00 | 74 | 25 | 23.0 | 2.54 | .04 | .5467 | .6519 | | | |
| | | 27 | 0 | | | | 2.56 | .02 | .5533 | .3960 | | .6149 | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| Totals | | 24 | 46 | 1580 | | | 1.66 | 1.66 | .5533 | | 1.1682 | .6149 | |

NOTE: Record the exact time of the following: First appearance of surface water, 40". All depressions filled, 5' 30". Start of drip into collector, 4' 8". Final disappearance of surface-water film after rainfall ceased, 30' 50". Record other remarks pertinent to run under "General Notes" on form A.

In the block headed "CALIBRATION RUNS" are recorded the "Starting time," "Ending time," "Duration," and the gage reading ("Gage rdg.") taken just before and just after each initial and final calibration run. The pressures employed in the tank and line gages and the disks used in the sprinkler nozzles are also entered in the designated spaces. The rainfall in inches depth per hour for each of the calibration runs is calculated by dividing the difference in the point gage readings by the ratio of the plot area to collector tank area and multiplying by the ratio of the time between readings to one hour. For example, taking the figures for the calibration runs shown in form B, the rainfall in inches per hour for the initial calibration run equals:

$$\frac{5.305-4.60}{3} \times \frac{60}{5} = \frac{0.705}{3} \times 12 = 2.82 \text{ inches per hour.}$$

Making the same calculations for the final calibration run, the application of rainfall was found to be at the rate of 2.84 inches per hour. Then $\frac{2.82 + 2.84}{2} = 2.83$, or the average rainfall in inches per hour for the two calibration runs, which is the rainfall rate to be used in making the infiltration-capacity determinations. The extra spaces in this block are for recording the results of any check calibration runs that may be made. The ratios of plot area to the rainfall and run-off collector tank areas should be recorded on the line opposite run-off.

In the block headed "RUN-OFF" the three columns headed "Remarks," "Reading time," and gage reading ("Gage rdg.") are the only ones that contain actual observed data. The other columns are used to record the rainfall, run-off, and infiltration results calculated from these observed data. The "Remarks" column is used to designate the condition observed, such as start of run, start of run-off, and end of run. In the columns headed "Reading time," the actual time of the observations is recorded in hours, minutes, and seconds to the nearest second. If a stop watch is used it will ordinarily be more convenient to record the hour or time of the start of run under the subcolumn headed hour ("Hr."), and under the subcolumns headed minute ("Min.") and second ("Sec.") to record the cumulative or elapsed time in minutes and seconds from the beginning of the run, as shown for run 58-A. Under gage reading the initial gage or water height at the start of the run is the first entry. As the run progresses each succeeding record is entered opposite the time at which the reading is taken.

The difference in time between readings is recorded to the nearest second in the column headed difference ("Diff."). Under "Mean time" is tabulated the actual time of the midpoint between readings for use in plotting the run-off and the infiltration rates after they have been determined. The differences between the point gage readings are calculated in the same manner as the time differences between readings and are recorded in the difference column under gage reading.

The readings entered in the cumulative ("Cum.") column under the heading run-off inches depth ("Run-off in. dph.") are obtained by dividing the cumulative gage reading, minus the value of the initial reading at the start of the run, by 3, the ratio of the collector tank area to the plot area. The run-off inches depth per hour is calculated by the same method as that employed in converting the rainfall into inches

depth per hour. For example, if the difference in gage reading is 0.05, the ratio of the plot area to the collector tank is, 3:1 and the corresponding time interval is 40 seconds, the run-off in inches per hour can be calculated in the following manner:

$$\text{Run-off in./hr.} = \frac{0.05}{3} \times \frac{3600}{40} = 0.01666 \times 90 = 1.50$$

If equal time intervals are used instead of equal run-off increments as in the above run the calculation can be simplified by determining a converting factor which, multiplied by the difference in gage reading, will give the run-off directly in inches per hour. For example, assume that a constant time interval of 30 seconds between readings is employed, then run-off in inches depth per hour can be determined by multiplying the difference in run-off between readings by the sum

$$\frac{3600}{3 \times 30}, \text{ or } 40.$$

Although this method appears to be no more accurate than the method employing equal run-off increments it has the advantage of greatly decreasing the time required in computing the run-off and rainfall rates and is therefore recommended for field use.

The cumulative precipitation ("Cum.ppt.") is obtained by multiplying the rate of rainfall in inches per hour, as determined during the calibration runs, by time expressed as hours or fractions of an hour. For example, in the sample run 58-A the amount of rainfall applied during the first 12 minutes and 50 seconds of the run was determined in the following manner:

$$\frac{770 \text{ total time interval, sec.}}{3600 \text{ sec. per hr.}} \times 2.83, \text{ av. amt. rainfall per hr.} = 0.6053.$$

In the block headed precipitation minus run-off ("Ppt-runoff") the cumulative ("Cum.") values are total retention, or the differences between the cumulative precipitation and the cumulative run-off at given intervals during the run. The values expressed in inches per hour ("In./hr.") are the differences between the rate of rainfall in inches per hour and the rate of run-off in inches per hour.

All calculations should be carefully checked before they are used. This can be done by making cross checks as the calculations are made, or by making cross checks on the totals at the bottom of the sheet after the tabulations have been completed. If additional space is required for the field runs the records should be carried forward to the continuation sheet, form C.

As indicated under "NOTE" at the bottom of the field sheet, the exact time of the first appearance of free water on the soil surface, the time of complete filling of all surface depressions, the start of drip into the collector tank, and the final disappearance of the water film after rainfall has been stopped should be carefully observed and recorded.

Cross-Section Field Sheet

In determining the length of runs that will be required to produce satisfactory infiltration measurements, it will often be helpful to plot the run-off results simultaneously with the recording of the run-off readings. For this purpose letter-size sheets of cross-section paper

(graduated 20 x 20 to the inch, 5th lines heavy) should be supplied. The results should be plotted either as cumulative run-off over time or as run-off rates over time, as shown in figures 9 and 10 in the section "Interpretation and Analysis of the Infiltration Data" (pp. 38-39). If run-off rate over time is plotted, a table of conversion factors, as described in the preceding section, should be compiled in order to permit the rapid calculation of the run-off rates.

Plotting of the run-off results while the runs are in progress will aid the operators in discovering irregularities caused by faulty installations or operating procedures, instrumentation failures, or errors in making readings. Most important, however, will be the value of the curves in affording the operators a visual picture of the results as a basis for determining the proper duration of runs.

INTERPRETATION AND ANALYSIS OF THE INFILTRATION DATA

The interpretation of the infiltration data will be greatly simplified if the relations between rainfall, surface run-off, infiltration, and such factors as initial and surface detention are fully understood. These relations are shown in the curves in figures 9 and 10, which were plotted from the data collected during an actual infiltration run near Friant, Calif. The original field data used in these figures are recorded in forms A and B, which are included in the preceding section, "Field Observations and Records."

The cumulative rainfall curve shown in figure 9 is calculated from the rainfall data obtained during the calibration runs. It shows the total duration of rainfall for the run and the total rainfall applied at any point during the run. The surface run-off curve is plotted from the actual observed run-off data and shows the cumulative total run-off at any time during the run. The start of run-off is indicated by the first vertical line of dashes; the amount of run-off when rainfall was stopped is indicated by the intersection of the run-off curve and the second vertical line of dashes; and the total run-off for the run is indicated by the intersection of the run-off curve and the third vertical line of dashes. The total retention curve is the difference between the total rainfall applied at any point during the run and the surface run-off up to that point. It represents all the water retained by the plot, either as interception, depression storage, infiltration, or run-off in transit, at any given time during the run.

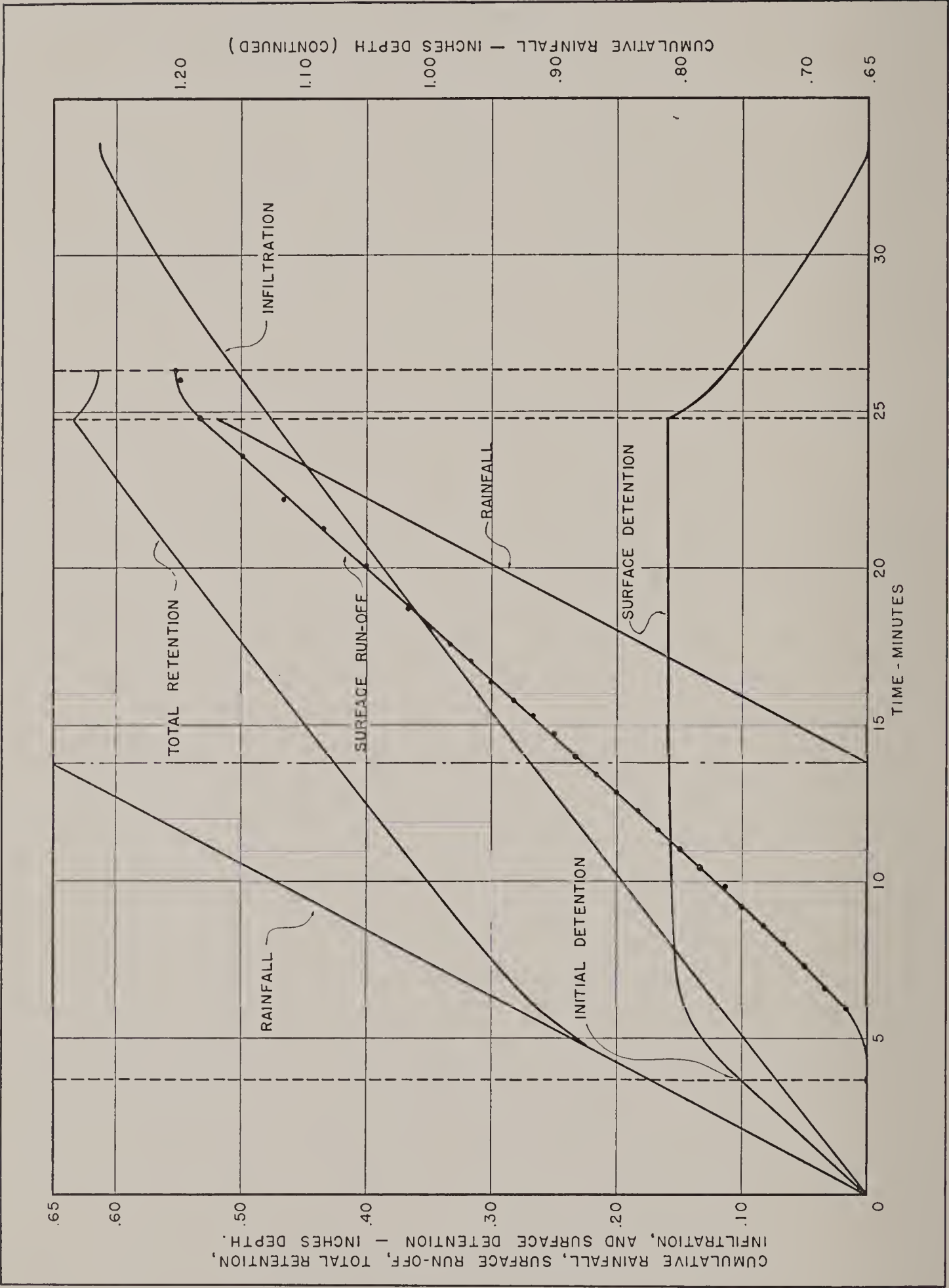


FIGURE 9.—Cumulative rainfall, surface run-off, total retention, infiltration, and surface detention in inches depth, for an infiltration run employing the North Fork infiltrometer.

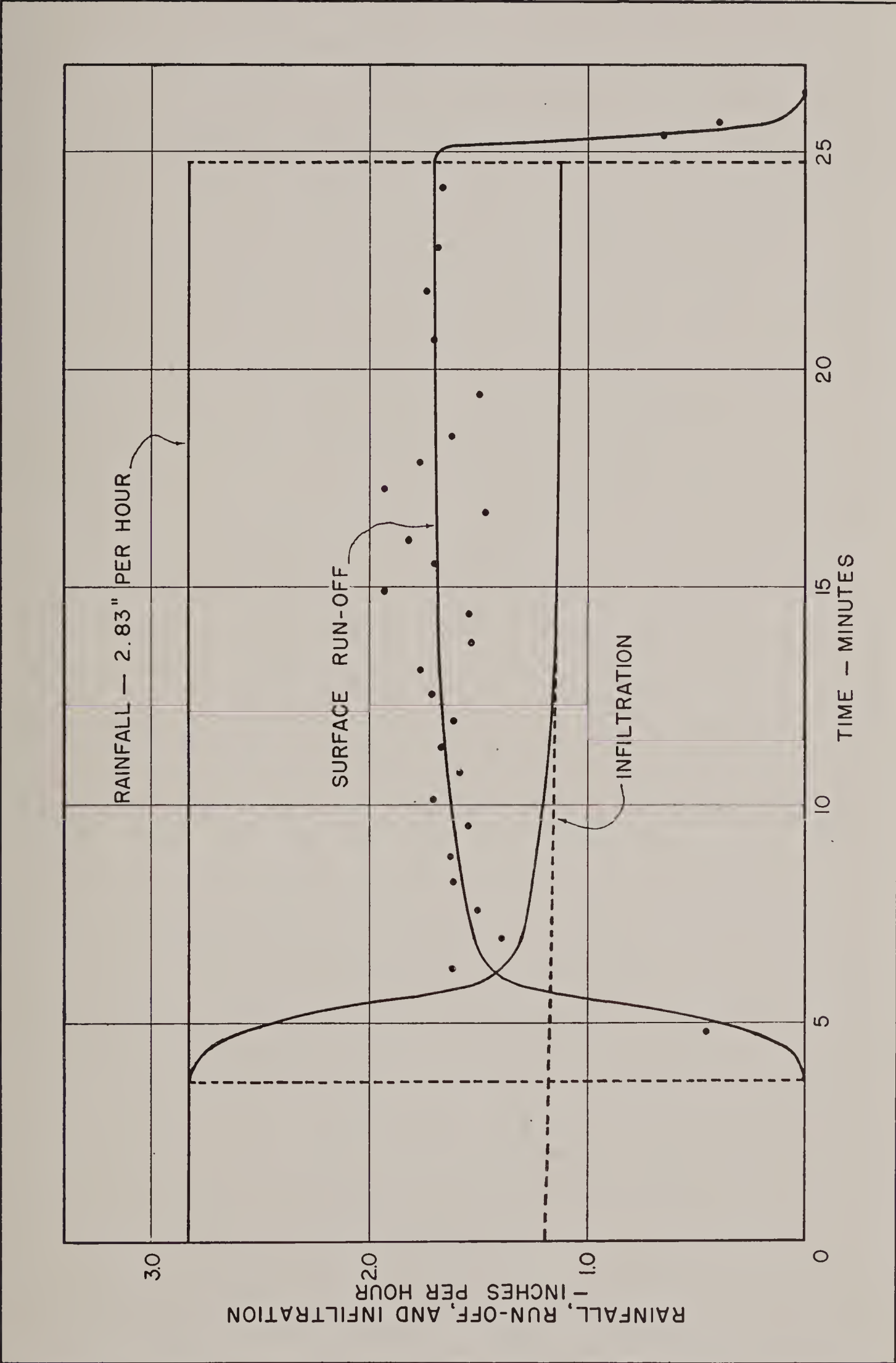


FIGURE 10.—Rainfall, surface run-off, and infiltration rates in inches per hour for the infiltration run shown in figure 9.

The infiltration curve is obtained by first plotting surface run-off rates, as shown in figure 10. The observed run-off rates are plotted over the mean time between readings and serve as the basis for drawing the horizontal part of the surface run-off curve. The portions of the run-off rate curve representing periods of rapid changes in run-off at the start and end of the run are based on the trend indicated by the cumulative run-off curve during those periods, as shown in figure 9. The infiltration rate curve, in figure 10, is the difference between the rate of rainfall and rate of run-off and corresponds to the total retention curve shown in figure 9. The infiltration indicated by this curve during the period before run-off has reached a constant rate includes, in addition to infiltration, all the water retained by the plot, such as depression storage and the water in transit as run-off. The infiltration rate at any time during the run after the rate of run-off has become constant or after the surface detention requirement has been met is a measure of the infiltration capacity of the soil at that instant. The infiltration-capacity curve for the run can, therefore, be completed by extending this flattened portion of the infiltration curve backward to the beginning of the run. The rate of infiltration during the period of rainfall application being known, it is a simple matter to construct the cumulative infiltration curve up to the end of the rainfall period, as shown in figure 9. The completion of the infiltration curve beyond the end of the rainfall period, however, requires the construction of a surface-detention curve.

Surface detention at any point during the run, as shown by the curve in figure 9, is equal to the cumulative rainfall less the cumulative run-off plus the cumulative infiltration up to that point, or $\text{Surface detention} = \text{Rainfall} - (\text{Run-off} + \text{Infiltration})$. It consists of depression storage plus interception and the surface run-off in transit. The chief value of the curve is that it shows initial detention and the volume of water on the plot surface at any given time during the run, particularly the amount of water remaining on the plot at the end of the rainfall and run-off periods.

In the run for which the data are shown there was approximately 0.16 inch of water on the plot when rainfall stopped. Run-off, however, continued for an additional period of 1 minute and 34 seconds, during which time the combination of run-off and infiltration decreased the volume of water on the soil by approximately 0.05 inch, leaving approximately 0.11 inch still on the plot. As the infiltration capacity of the soil at the end of the run was 1.12 inches per hour, or 0.0187 inch per minute, an additional period of at least 5 minutes and 53 seconds would be required for the complete disappearance of the surface water. Unless, however, the infiltration capacity of the soil over the entire area of the plot is the same, and unless the water remaining on the plot at the end of run-off is evenly distributed, the infiltration period must be somewhat longer than the minimum requirements. In the run under consideration the duration of the infiltration period after run-off had ceased was estimated, on the basis of the field observations, to be approximately 7 minutes and 16 seconds, and the surface-detention and infiltration curves were drawn accordingly.

The surface-detention curve also serves as a useful basis for estimates of such factors as velocity of flow, depression storage, and run-off

in transit at any given point during the run. For example, depression storage for the plot can be estimated in the following manner: assuming first that during the period of run-off after the rainfall has been stopped, the run-off made a contribution to the depression storage equal to one-half the infiltration during this period; then the difference between the surface detention at the start of the period and the run-off during the period, plus one-half the infiltration during the period, gives a relatively close approximation of depression storage which, for the data shown, is $0.16 - (0.02 + 0.015)$, or 0.125 inch.

The larger number of infiltration studies will be primarily concerned with obtaining measurements of the infiltration capacity of the soils or strata being sampled and therefore may not require the construction of cumulative curves, such as shown in figure 9, other than for rainfall and run-off. The infiltration capacity of the sampling site can be determined by plotting the infiltration rates directly from the field data, as shown in figure 10. In order to obtain consistent and comparable results, however, the infiltration rates used in determining the infiltration capacity for the individual runs should always be the average of the infiltration rates during the first 20-minute interval after surface run-off has attained a comparatively constant rate of flow.

The infiltration run shown in figures 9 and 10 is one of the early runs made before the 20-minute constant run-off interval was set up as standard for determining infiltration capacities. In the infiltration curves shown in figure 10, the infiltration capacity for the run was estimated as 1.13 inches per hour and was determined by calculating the average infiltration rates during the 14- to 24-minute interval of the run, which was the first 10-minute period having an approximately constant rate of run-off. Had this run been of sufficient duration to permit the use of a 20-minute period of run-off in the calculation for the infiltration capacity, the result would have been approximately 0.005 inch per hour lower than that based on the 10-minute interval.

In determining the influence on infiltration of such factors as duration and intensity of rainfall, interception, vegetation cover, and cultivation, curves similar to those shown in figures 9 and 10 will prove very useful. For example, figure 9 shows that the proportion of surface run-off is increased and the proportion of infiltration decreased with increased duration of the run. In the run shown, 1.168 inches of rainfall were applied in 24 minutes and 46 seconds, resulting in 0.553 inch, or 47 percent, run-off and approximately 0.615 inch, or 53 percent, infiltration. The total duration of run-off was 22 minutes and 40 seconds, or 92 percent of the total duration of rainfall; while the total infiltration period was approximately 33 minutes and 36 seconds, or 136 percent of the total duration of rainfall.

If the run had been continued for only 15 minutes, the curve shows that approximately 0.71 inch of rainfall would have been applied; 0.281 inch, or 40 percent, of which would have been run-off and 0.429, or 60 percent, of which would have been infiltration. The duration of run-off would have been approximately 12 minutes and 54 seconds, or 86 percent of the total duration of rainfall; and the period of infiltration would have been approximately 23 minutes and 50 seconds, or 159

percent of the total duration of rainfall. The effects of durations exceeding the actual interval of the run can be calculated in a similar manner. Thus by careful interpretation of the results, as shown by the above calculations, the influence of duration of rainfall on total run-off and infiltration can be quite easily and accurately determined for individual plots.

The influence of rainfall intensity, interception, litter cover, cultivation, and similar factors on infiltration can likewise be measured by comparing the results of runs on a plot where factors other than the one being studied are held constant. For example, to determine the influence of litter on infiltration, the moisture content of the soil would be brought to field capacity and an infiltration run would be made with the litter in place. The plot would then be covered to prevent surface evaporation until the soil moisture had again reached equilibrium, at which time a repeat run would be made with the litter removed, but with other conditions of the first run duplicated. The results of the two runs could then be plotted, as previously shown in figures 9 and 10, and the influence of the litter could be determined by measuring the differences in infiltration rates during equivalent time intervals after the run-off in both runs had obtained a constant rate.

The influence of initial detention, depression storage, surface detention, and total infiltration can also be determined by comparing the cumulative infiltration and surface detention curves for the two runs. In this regard it should be noted that an increase in surface detention would actually serve to increase the total infiltration for a run. Thus if a litter cover resulted in an increased surface detention during a given storm, it could actually increase total infiltration and decrease surface run-off without changing the infiltration capacity of the soil.

As in the studies of litter cover, the curves can be used with equal effectiveness in studying the influence of interception, cultivation, and other factors on infiltration. The greatest advantage in their use is that they show whether a given treatment or condition actually alters or affects the infiltration capacity of the soil or merely results in some modification of the run-off and infiltration relations, such as would result from an increase or decrease in surface detention.

In the interpretation of the infiltration data it should be remembered that the measurements of total run-off, total infiltration, initial detention, and surface detention are limited by the size of the plot and therefore have only comparative or qualitative value in their application to larger areas. Likewise the determinations of the influence of such factors as herbaceous vegetation, forest litter, and cultivation on total run-off and total infiltration have only qualitative application.

The measurement of the infiltration capacity of the soil and of the influence of such factors as forest litter and soil moisture upon the infiltration capacity are, on the other hand, actual quantitative measurements and are the same as would be obtained under similar conditions with natural rainfall. The application of the infiltration-capacity measurements to larger areas, however, is dependent upon the adequacy of sampling and upon the user's knowledge of the influence on surface run-off and total infiltration of such other factors as area, degree of slope, land use, roughness of surface, and rainfall intensity.

When the field work for a study has been completed and the data tabulated, the data should be submitted to the type of analysis best suited to permit determinations of the mean infiltration capacities of the strata and substrata of the sampling universe, together with the standard deviations and the range in infiltration-capacity measurements of the individual sampling units. In addition, an analysis should be made by strata or substrata to show any correlation which may exist between such factors as vegetation cover, land use, slope, exposure, and various physical characteristics of the soil. The method of analysis used will in part be dependent upon the objectives of the study and upon the sampling procedures followed. Unless those responsible for working up the data are familiar with statistical procedures it would be well to obtain the assistance of a statistician in determining the method of analysis to be employed.

In the final presentation of the data for most studies, the greatest emphasis will ordinarily be placed on the infiltration-capacity measurements obtained when the moisture content of the soil is at or near field capacity. These measurements, however, when used in conjunction with a master curve for soil moisture, will permit accurate estimates of infiltration capacity under any soil-moisture condition. The presentation of the infiltration data will be much more effective and often greatly simplified if graphic illustrations are used.

REPORTS

Upon the completion of each study a detailed, descriptive, and concise report should be prepared to supplement the field data. This report should include a complete description of each infiltration stratum or substratum in the sampling universe, compiled from the notes and observations collected during individual runs and during the preliminary reconnaissance of the area. A description of any of the physiographic, biotic, or climatic features of the sampling strata influencing infiltration, particularly land use and all available rainfall and run-off data, should also be included.

In addition, the mean infiltration capacities of the various strata comprising the sampling universe, the variation in the infiltration capacities of the sampling sites within each stratum, and the probable reliability or accuracy of the results should be given. Areas of low and high infiltration capacities within the strata, their extent and position with reference to the natural drainages, and their possible significance in the water problems of the area should be described. Detailed and specific descriptions of all other characteristics or conditions influencing infiltration should likewise be included.

The report should also indicate the effects of differences in vegetation, land use, and cultural treatments on the infiltration and run-off relations of the area. The possible benefits to be derived from increases in the infiltration capacities of the soils that could be brought about by regulation or treatment and possible methods of effecting these increases should be discussed. Finally, the report should summarize and interpret any of the findings of the study capable of contributing to a better understanding or greater knowledge of the fundamental principles of infiltration and of the factors influencing it.

SUMMARY

This publication describes the North Fork infiltrometer, a portable apparatus developed primarily to determine the infiltration capacity of soils by sampling methods. A description of the instrumentation and its application, complete specifications for its fabrication, and instructions for the sampling and operating procedure are given.

Suggested procedures and sample forms for recording the infiltration data are included in the instructions. The relations of rainfall intensity and duration, surface run-off, surface detention, and depression storage to infiltration are shown by a series of curves based on data from actual field runs. The interpretation and application of infiltration measurements and the preparation of the final reports are also discussed.

It is pointed out that the value of infiltration data collected through the use of any sampling device will depend not alone upon the adequacy and accuracy of the instrumentation, but also upon the operator's knowledge of the fundamental principles of infiltration and the factors influencing it, his circumspection in operating technique and accuracy of measurements, and the completeness and reliability of recorded field data and observations.

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⁵This reference list, which includes only a few of the more pertinent publications pertaining to infiltration, is included for the convenience of the field operators.

APPENDIX

To facilitate purchasing the infiltrometer, the specifications and list of materials needed for a complete one-plot outfit⁶ are included in the succeeding pages. The number required of each of certain parts of the apparatus will depend upon the number of plot units to be used and upon the operating procedures to be followed (pp. 20-21). The purchasing of the infiltrometer equipment should, therefore, be supervised by those responsible for the planning and organization of the field work.

SPECIFICATIONS FOR PLOT EQUIPMENT (FIGURE 11)

Purpose

To delimit sampling areas or plots, 1 foot wide by $2\frac{1}{2}$ feet long, horizontal measurement, on slopes from 0 to 100 percent.

Equipment for Plot

Equipment consists of two galvanized iron side walls, two end cut-off walls, one run-off trough, one run-off trough cover, and three brass spacer rods and bolts, constructed in accordance with figure 11.

Description

Side walls.—One left and one right wall, each 48 inches long by 6 inches high, 14-gage galvanized iron, punched for $\frac{1}{4}$ -inch spacer rod bolts, bottom edges sharpened and top edges with 60° outside bevel.

End cut-off walls.—One 7 and one 6 inches high by $12\frac{1}{4}$ inches wide inside dimensions, 14-gage galvanized iron, sharp right-angle bends at corners, top edges with 60° outside bevel, and bottom edges sharpened⁷.

Run-off trough.—Eighteen-gage galvanized iron, $11\frac{15}{16}$ inches wide outside dimensions, all seams and soldering inside so that trough will fit snugly between the plot walls without forcing, sharp right-angle bend on lip at trough mouth, $\frac{3}{4}$ -inch brass drain outside diameter fitted to permit complete drainage.

Run-off trough cover.—Eighteen-gage galvanized iron, 13 inches wide, 1 inch high, 18 inches long, fitted with $\frac{3}{4}$ -inch 24-gage spring brass locks, $\frac{3}{8}$ -inch lip at upper end with 60° inside bevel⁸.

Spacer rods.—Three $\frac{1}{2}$ - by 12-inch brass rods, tapped for $\frac{1}{4}$ - by $\frac{1}{2}$ -inch brass screwhead bolts. Allowable deviation in length ± 0.01 inch.

Workmanship and Materials

Workmanship to be of high quality and of finished appearance. Materials to be free from defects, and fabricated parts to be capable of fitting together as shown in assembled view, figure 11. Allowable deviation in dimensions $\pm 1/16$ inch unless otherwise indicated.

⁶The Flood Control Coordinating Committee of the U. S. Department of Agriculture is making a detailed study of certain parts of the North Fork infiltrometer equipment. As an outcome of this study some modification in the instrumentation, particularly in the spray equipment, may be suggested. The infiltrometer as described in this publication has, however, been adopted by the Committee as the official instrument for departmental work.

⁷If an apparatus is to include the equipment for two or more plots, it may not be necessary to order two end cut-off walls with each plot unit, as ordinarily the plots will not be set up on all low or all steep slopes at the same time.

⁸Not more than two covers will be required for a single sampling outfit, since they can be moved from plot to plot as the runs are made.

Number Required

Equipment for from four- to six-plot units recommended for use with each infiltrometer (see pp. 6 and 20 to 21).

Cost

Cost of plot units in lots of one to two, approximately \$10.50
Cost of plot units in lots of three to six, approximately 9.00

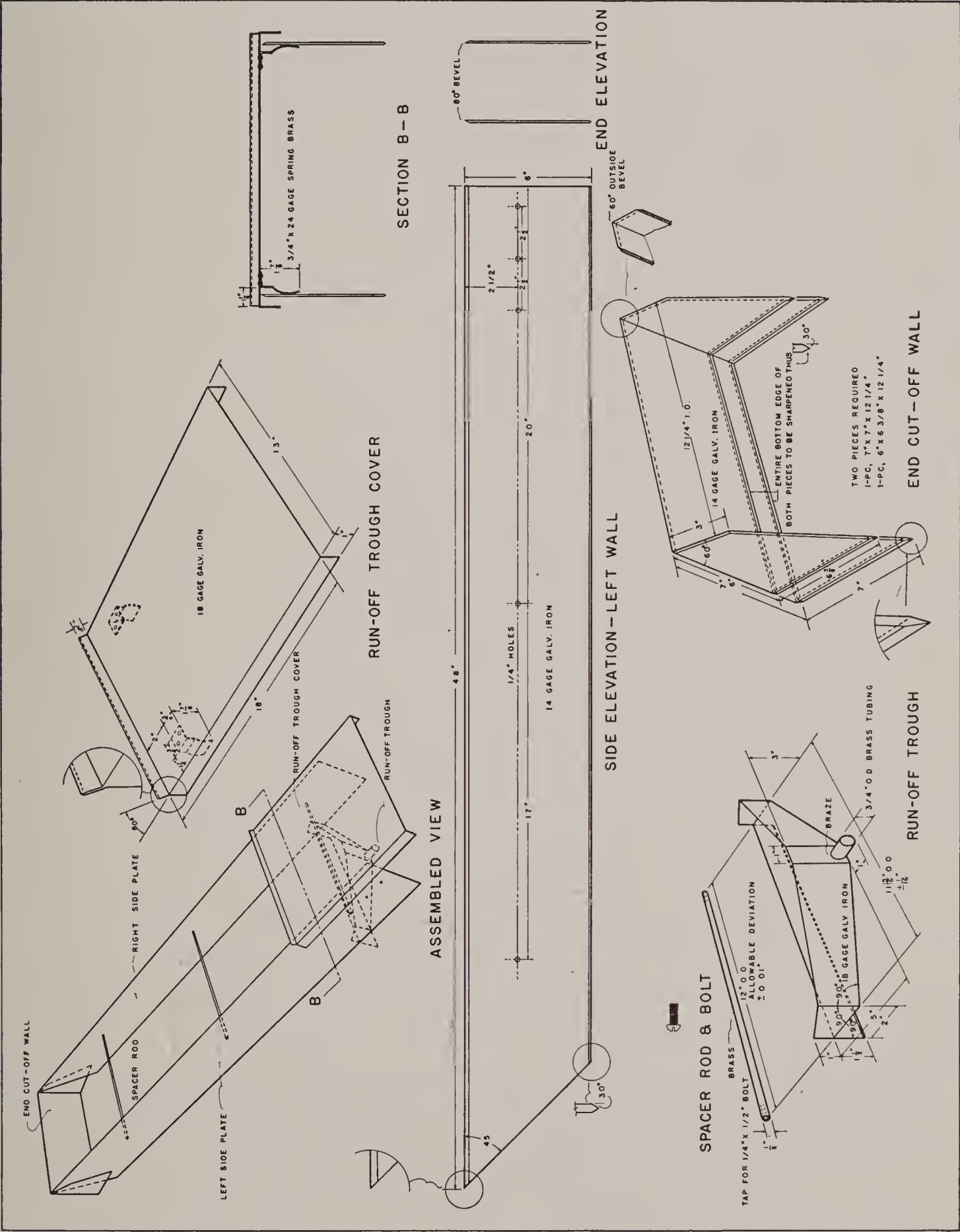


FIGURE 11.—Plot equipment, including side wall, end cut-off walls, run-off trough and cover, and brass spacer rods.

SPECIFICATIONS FOR RAIN PAN (FIGURE 12)

Purpose

To fit over the plot to catch and permit the measurement of rainfall from the exact area delimited by the plot walls during the infiltration runs.

Equipment

One pan, constructed in accordance with figure 12.

Description

Twelve and $\frac{3}{4}$ inches wide, 1 inch deep at back, $2\frac{1}{4}$ inches deep at front, 47 inches long, 28-gage galvanized iron, sides slightly sloped to permit easy fit over plot walls, apex of angle on sides and end walls to be sharp to provide a satisfactory rain-splitting edge. The distance between rain-splitting edges on sides should not be less than 12 inches so that when pan is in place the apex of its cutting edges is directly above the corresponding edges of the plot. Corners of pan to be soldered,

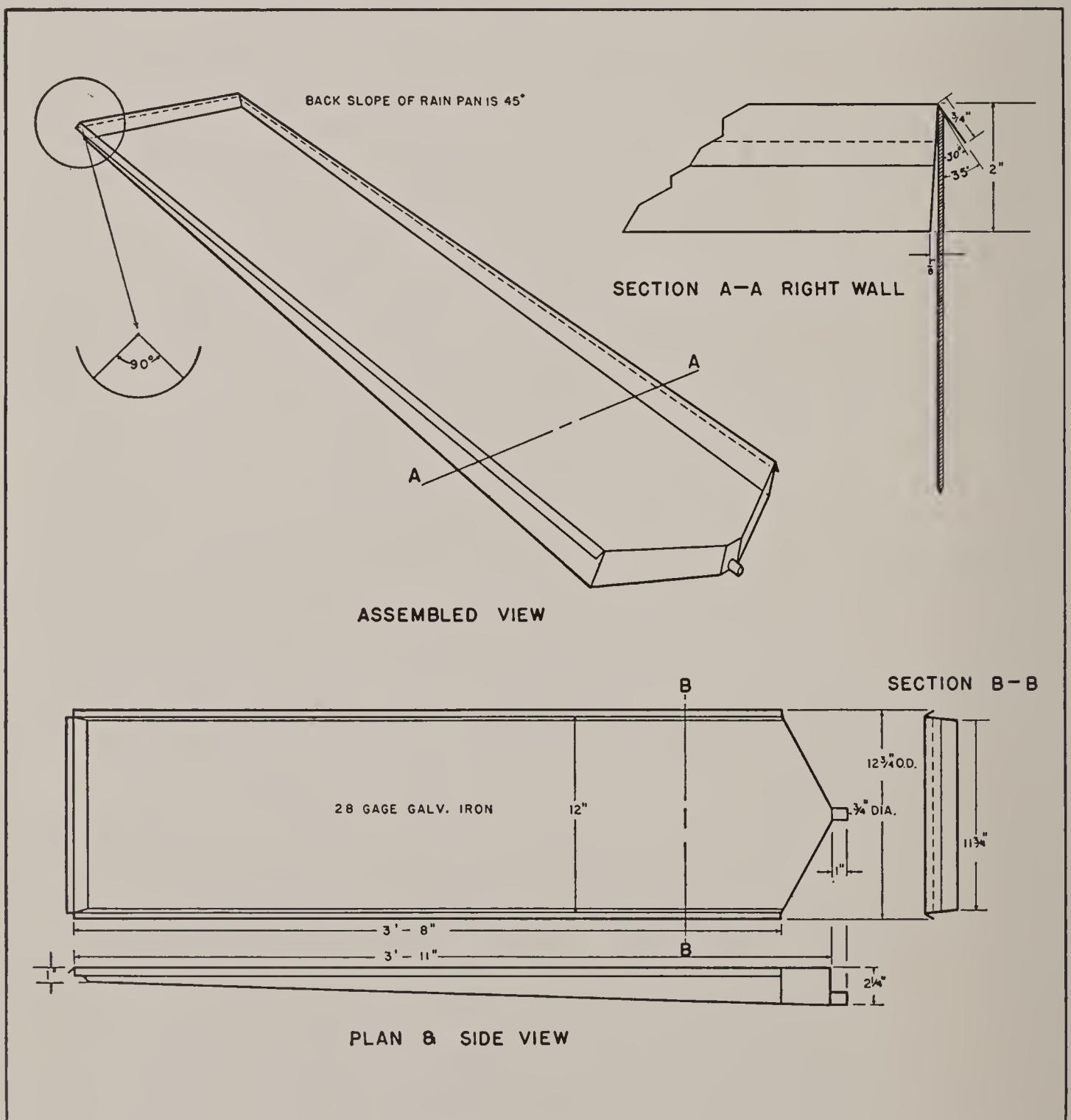


FIGURE 12.—Rain pan.

the distance between cutting edges at the corners to be exactly 12 inches ± 0.01 inch. Drain to be installed so as to permit free and complete drainage.

Workmanship and Materials

Workmanship to be of high quality and of finished appearance. All materials to be free from defects. Allowable deviation in dimension $\pm 1/16$ inch, unless otherwise indicated.

Number Required

One pan required with each infiltrometer.

Cost

Cost per pan, approximately \$3.50.

SPECIFICATIONS FOR RAINFALL AND RUN-OFF COLLECTOR TANK (FIGURE 13)

Purpose

To collect and hold for measurement the rainfall and run-off from the infiltration plots.

Equipment

Equipment consists of one collector tank, fitted with angle-iron gage support, stillwell insert, tank cover, drain pipe, and rubber tubing for coupling, constructed in accordance with figure 13.

Description

Collector tank.—Twenty-gage galvanized iron, 15 inches deep, $12\frac{3}{8}$ inches ($\pm 1/64$ inch) inside diameter and all seams soldered. Angle-iron support to be installed to hold the point gage in a vertical position in the center of the tank without forcing the circumference of tank out of a true circle. Cover of tank to consist of two pieces of sheet metal held in place by the point gage. Stillwell brackets riveted and soldered to sides of tank, stillwell insert removable.

Accessory equipment.—One piece No. 0.035 seamless brass tubing $\frac{3}{4}$ -inch outside diameter by 6 feet long. One piece of $\frac{5}{8}$ -inch flexible rubber tubing, 10 feet long.

Workmanship and Materials

Workmanship to be of high quality and of finished appearance. Material to be free from defects. Tank to permit accurate measurements of rainfall or run-off within ± 0.01 inch depth. Allowable deviations in dimensions of equipment requiring fabrication $\pm 1/16$ inch unless otherwise stated.

Number Required

One collector tank complete with accessories required with each infiltrometer.

Cost

Cost of collector tank, approximately \$4.50; accessories, approximately \$2.00; total, approximately \$6.50.

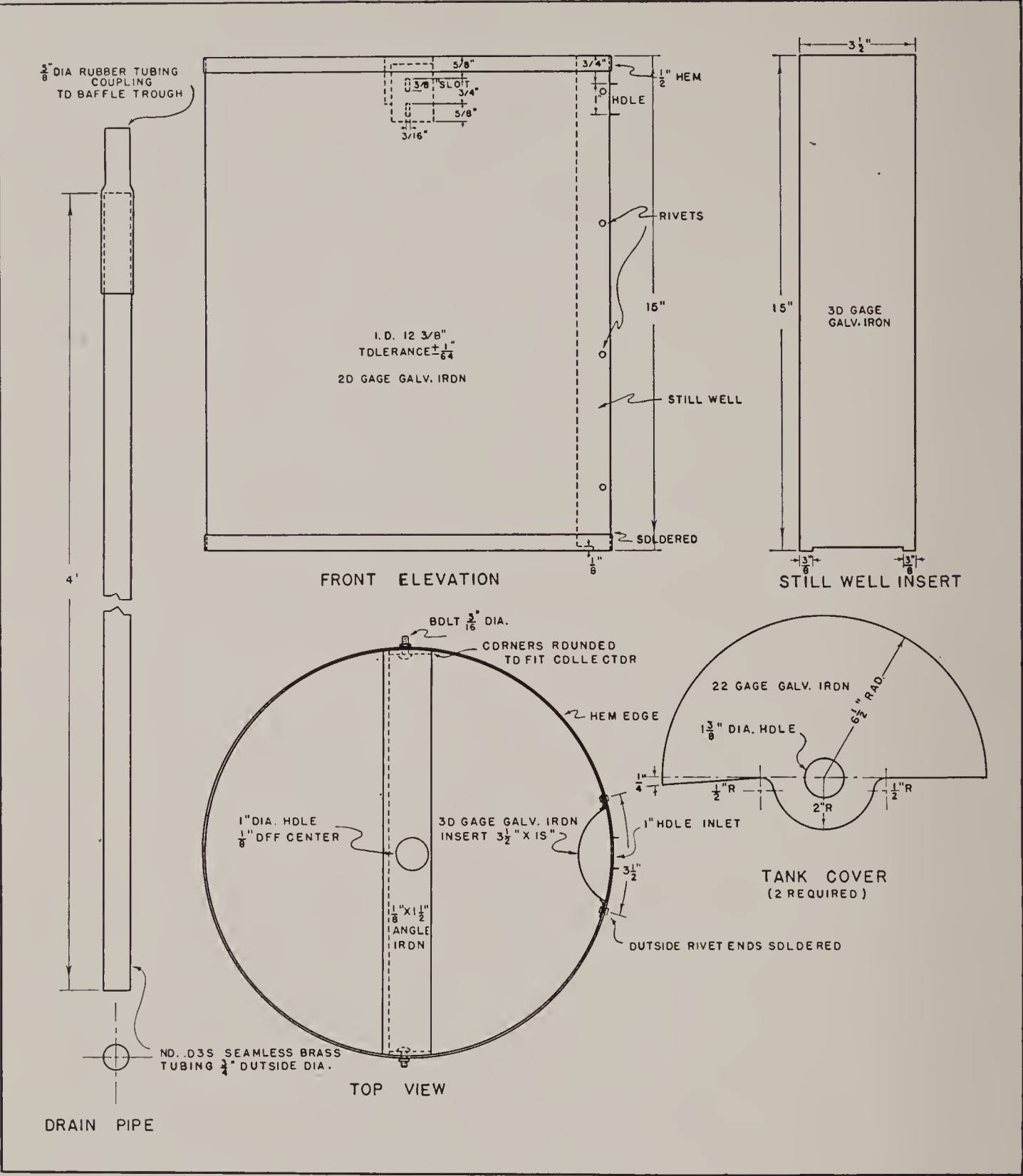


FIGURE 13.—Rainfall and run-off collector tank.

SPECIFICATIONS AND LIST OF MATERIALS FOR SPRINKLER
HEAD ASSEMBLY (FIGURE 14)

Purpose

To simulate rainfall in making infiltration runs.

Equipment

Equipment consists of four fog nozzles, one set of nozzle disks, galvanized iron pipe fittings, and three support stakes and clamps, constructed in accordance with figure 14.

Description

Fog nozzles.—Four brass 45° angle fog nozzles of a type similar to those supplied with the standard garden pressure sprayers. Each

nozzle to be equipped with removable brass screen and water agitator to adapt it for throwing either a spray or solid stream. Tapped for $\frac{1}{4}$ -inch pipe fittings.

Nozzle disks.—One set of disks as listed below. Each disk to be drilled in true center with edges of orifices honed smooth. The disks to be made to insure a snug fit ($\frac{1}{60}$ -inch tolerance) in fog nozzles and so that the orifice of a disk in place will always be concentric with the inside circumference of the removable head of the nozzle.

- 10 32-gage spring brass disks, with orifice opening of 0.0240 inch (No. 73 drill)
- 10 32-gage spring brass disks, with orifice opening of 0.0310 inch (No. 68 drill)
- 10 30-gage spring brass disks, with orifice opening of 0.0410 inch (No. 59 drill)
- 10 30-gage spring brass disks, with orifice opening of 0.0520 inch (No. 55 drill)
- 10 30-gage spring brass disks, with orifice opening of 0.0625 inch (No. $\frac{1}{16}$ drill)
- 10 30-gage spring brass disks, with orifice opening of 0.0730 inch (No. 49 drill)
- 10 30-gage spring brass disks, with orifice opening of 0.0820 inch (No. 45 drill)
- 10 30-gage spring brass disks, with orifice opening of 0.0935 inch (No. 42 drill)

Pipe fittings.—As listed below.

- 1 piece of $\frac{1}{4}$ x 16 inch galvanized iron pipe, both ends threaded
- 2 pieces of $\frac{1}{4}$ x $6\frac{3}{4}$ inch galvanized iron pipe, both ends threaded
- 1 piece of $\frac{1}{8}$ x 3 inch galvanized iron pipe, one end threaded
- 6 $\frac{1}{4}$ x 2 inch galvanized iron nipples
- 4 $\frac{1}{2}$ x $2\frac{1}{2}$ inch galvanized iron nipples
- 1 $\frac{1}{4}$ inch galvanized iron pipe tee
- 2 $\frac{1}{2}$ x $\frac{1}{2}$ x $\frac{1}{4}$ inch galvanized iron pipe reducer tees
- 2 $\frac{1}{4}$ inch, 90° galvanized iron pipe elbows
- 4 $\frac{1}{4}$ x $\frac{1}{2}$ inch, 90° galvanized iron pipe reducer elbows
- 1 $\frac{1}{8}$ x $\frac{1}{4}$ inch galvanized iron pipe reducer

Support stakes.—Three $1\frac{1}{2}$ -inch angle-iron stakes, $\frac{1}{8}$ inch thick, 30 inches long, and slotted for mounting clamps. Three $\frac{3}{8}$ -inch cold rolled iron or steel rod mounting clamps equipped with winged lock nuts and hammered end supports. Stakes and clamps to be galvanized after fabrication.

Workmanship and Materials

Workmanship to be of high quality and of finished appearance. Materials to be free from defects. Allowable deviations in dimensions of equipment requiring fabrication $\pm \frac{1}{16}$ inch unless otherwise specified. Dimensions of prefabricated equipment to conform to commercial standards, inside ends of pipe fittings to be reamed.

Number Required

One sprinkler-head assembly required with each infiltrometer. Three support stakes complete with clamps required for each set of plot equipment included in the infiltrometer.

Cost

Cost of sprinkler-head assembly complete with pipe fittings, nozzles, and disks, approximately \$6.50. Cost of support stakes complete with clamps, per set of three, approximately \$4.00.

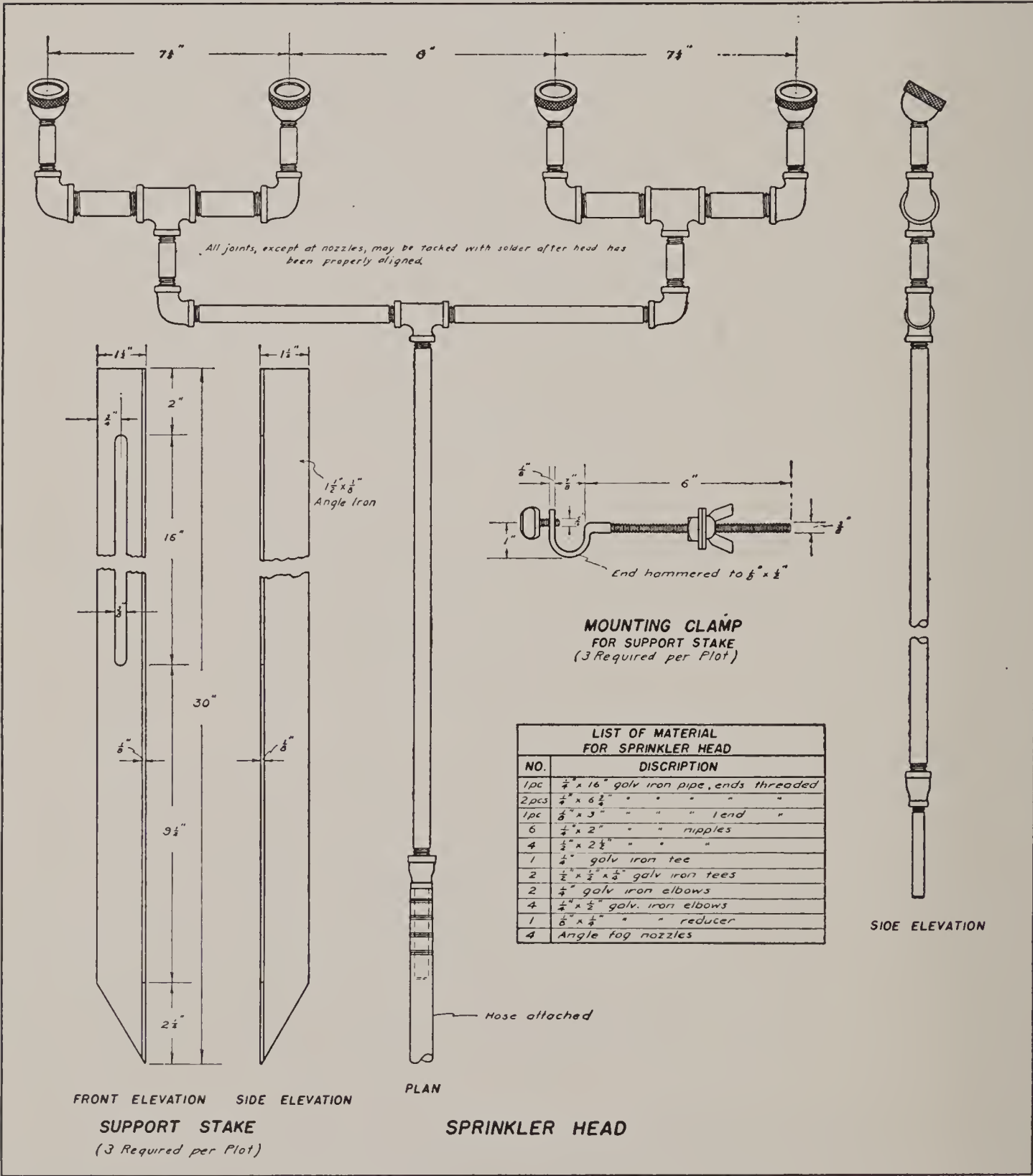


FIGURE 14.—Sprinkler-head assembly and support stakes.

SPECIFICATIONS AND LIST OF MATERIALS FOR PRESSURE-LINE ASSEMBLY (FIGURE 15)

Purpose

To regulate water pressure during infiltration runs.

Equipment

Equipment consists of one pressure gage, one pressure regulator, galvanized iron pipe fittings, and one support bracket, constructed and assembled in accordance with figure 15.

Description

Pressure gage.—Zero to 15-pound pressure gage with 3½-inch face, ¼-pound graduations, bronze bushed movements, adjustable zero point. Equipped with brass petcock and standard ¼-inch female connections and constructed of rustproof materials. Gage to be sensitive to 1/32-pound fluctuations in pressure and to have ¼-pound accuracy over full range of its scale.

Pressure regulator.—Precision pressure regulator, set to reduce 30 to 5 pounds and permitting rapid and accurate adjustments between 1 and 15 pounds. Equipped with sensitive diaphragm and ¼-inch standard female pipe connections and constructed of forged bronze or rustproof materials. To be capable of maintaining pressures within limits of 1/32 pound. Weight not to exceed 3 pounds.

Pipe fittings.—As listed below.

- 2 15/16 x 1 inch machine bolts, nuts, and lock washers
- 1 piece of ¼ x 13 inch galvanized iron pipe
- 5 ¼ x 2 inch galvanized iron pipe nipples
- 2 ¼ x 3 inch galvanized iron pipe nipples
- 2 ¼ inch 90° galvanized iron pipe elbows, beaded
- 1 ¼ inch galvanized iron pipe tee
- 1 ¼ inch galvanized iron ground joint union
- 2 ¼ inch brass lever handle cut-out cocks

Support bracket.—Constructed of wrought iron in accordance with drawing in figure 15, and equipped with two ½- x 3/16-inch screw-head bolts.

Workmanship and Materials

Pressure gage and pressure regulator.—To be of best commercial quality and free from defects. Any parts developing defects due to material or workmanship within 1 year after purchase to be replaced without cost. Precisions to be within the limits stated under "Description."

Pipe fittings and support brackets.—Material to be free from defects, inside ends of all pipe fittings to be reamed, and dimensions to conform to commercial standards.

Number Required

One pressure-line assembly required with each infiltrometer.

Cost

Pressure gage, approximately \$5.00; pressure reducer, approximately \$2.50; pipe fittings and support bracket, approximately \$2.00. Total cost of assembly, about \$9.50.

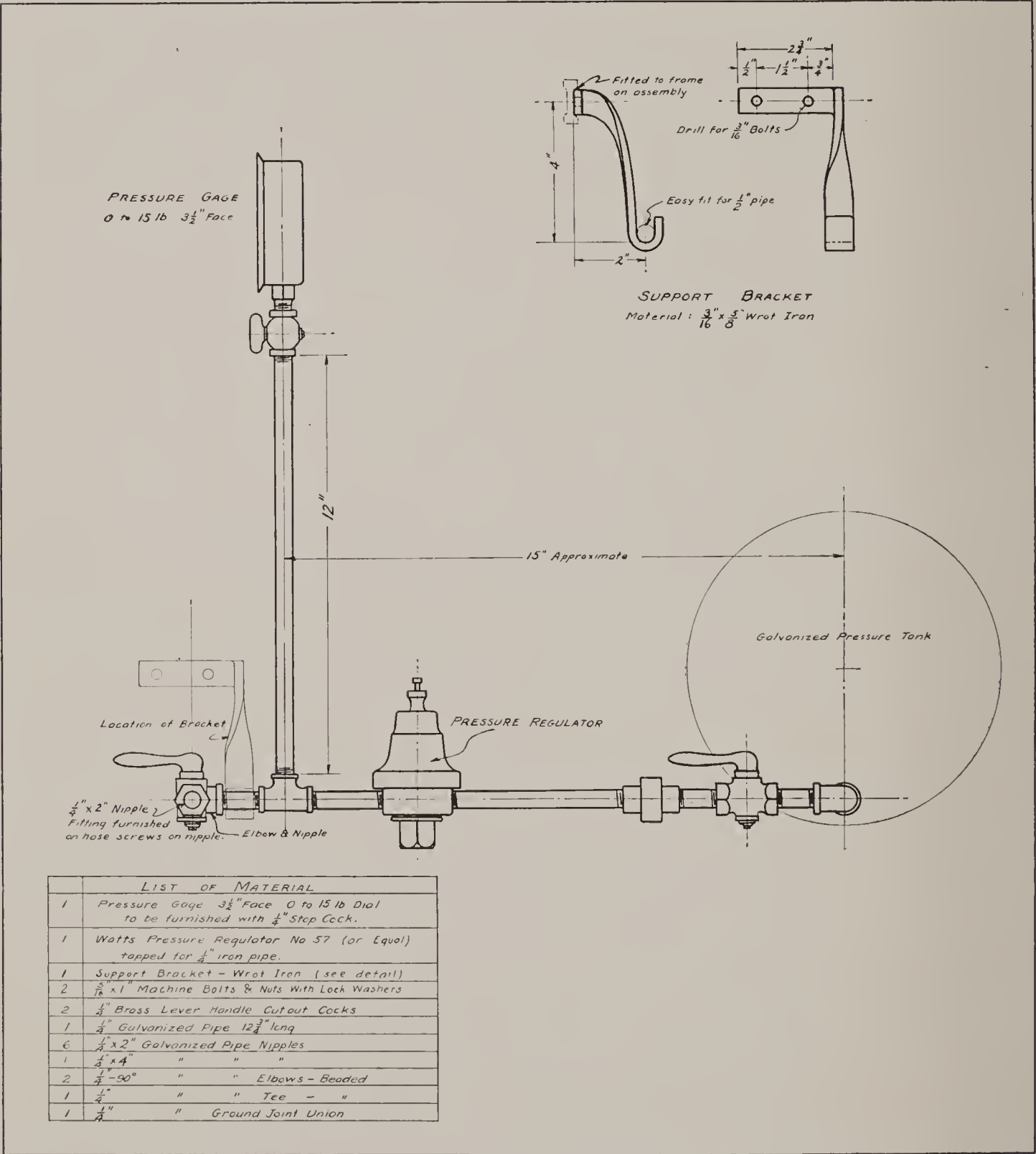


FIGURE 15.—Pressure-line assembly.

SPECIFICATIONS FOR WINDBREAKER FRAME (FIGURE 16)

Purpose

To support windbreaker tent during infiltration runs.

Equipment

Two bottom supports, two spacer rods, four tie pins, four uprights, two top side supports, two end cover supports, and one center cover support, constructed, in accordance with figure 16, of black iron and galvanized after fabrication.

Description

Bottom supports.—One right and one left, $1\frac{1}{2}$ - x $\frac{1}{8}$ -inch bottom angle-iron supports, 72 inches long, punched for spacer rods and equipped with $\frac{7}{16}$ x $9\frac{1}{2}$ -inch iron corner rods welded in place.

Spacer rods.—Two $\frac{7}{16}$ -inch iron rods, 47 inches long, hook ends tapped for $\frac{1}{8}$ -inch lock bolts.

Tie pins.—Four $\frac{7}{16}$ -inch pointed iron rods, 12 inches long with a 2-inch loop at the tops.

Uprights.—Four pieces of $\frac{3}{8}$ - x 54-inch iron pipe, with a $\frac{3}{8}$ - x 6-inch piece welded to one end, and all openings reamed.

Top supports.—Two 70 inches long, constructed of $\frac{3}{8}$ -inch pipe fitted with a center iron cross and 5-inch nipple and $\frac{7}{16}$ -inch end rods welded in place and bent to proper angle.

Cover supports.—One center, two end, $\frac{7}{16}$ -inch iron support rods, 48-inch span, 24 inches high. End supports to be fitted with collars welded to the rods 5 inches from bottom. Top of center support to have a $3\frac{1}{2}$ -inch angle in 18 inches, as shown in drawing.

Workmanship and Materials

Workmanship to be of high quality and of finished appearance. Material to be free from defects, and finished parts to be capable of fitting together without undue friction, as shown in assembled view, figure 16⁹. Allowable deviation in dimensions other than those affecting the fitting together of the equipment $\pm \frac{1}{4}$ inch. Dimension of prefabricated material to conform to commercial standards.

Number Required

One windbreaker frame required for each infiltrometer.

Cost

Total cost of frame, including pins and galvanizing, approximately \$17.

⁹It should be noted that the specifications are for a frame built so that the uprights will be in a vertical position when placed on a 20-percent slope. If sampling is to be done on areas with slopes averaging appreciably more or less than 20 percent, the windbreaker frame and tent should be constructed to permit vertical installation on the average slope.

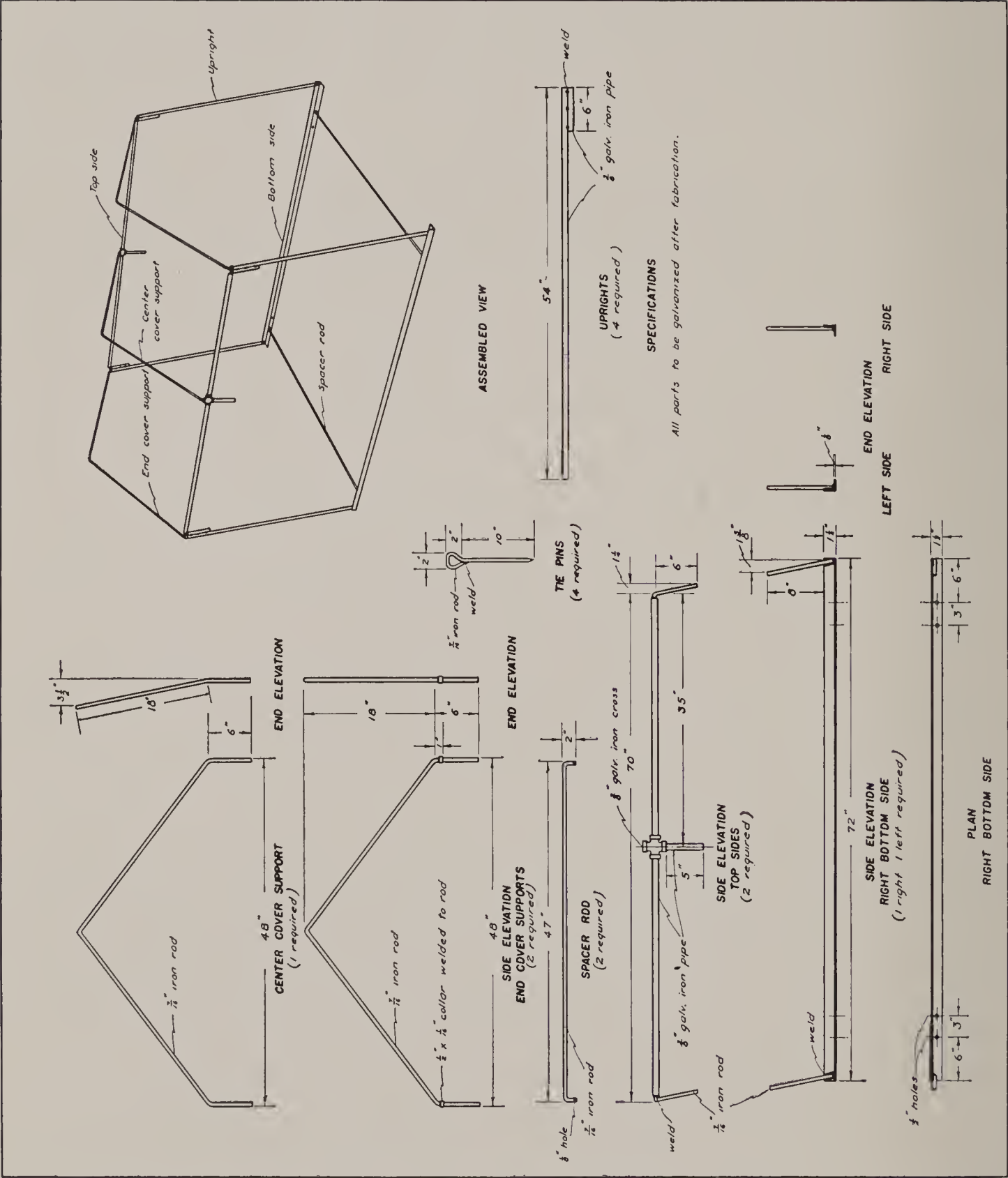


FIGURE 16.—Frame for the windbreaker tent.

SPECIFICATIONS FOR WINDBREAKER TENT (FIGURE 17, A)

Purpose

To fit over plot equipment when installed in the field to prevent wind disturbances during runs.

Equipment

One tent constructed in accordance with figure 17, A.

Description

Seventy-three inches long, 52 inches wide, 76 inches high; vertical side walls 58 inches high; constructed of 10-ounce double-filled pre-shrunk canvas with all edges hemmed. Equipped with extra long front flaps and tying tabs¹⁰, 6-inch bottom flaps, and $\frac{3}{8}$ -inch brass grommets. A 16-inch slit about 4½ feet high to be made in the center seam in the back of the tent and a similar slit about 2 feet high to be made in one of the side seams at the back to permit observation during runs. Tent to be built on bias so that end walls will be vertical when placed on a 20-percent slope (bias 15 inches in 76 inches height).

Workmanship and Materials

Workmanship to be of high quality and of finished appearance. Material to be of best quality and free from defects. Finished tent to fit properly over tent support; allowable deviation in measurements $\pm \frac{1}{2}$ inch.

Number Required

One tent required with each infiltrometer.

Cost

Total cost, approximately \$10.

¹⁰ A 6-foot zipper fastener can be substituted for the double ties on the front flaps of the tent; and 16-inch zippers can be placed in the observation openings in the tent, if desired. This would increase the cost of the tent about \$5.

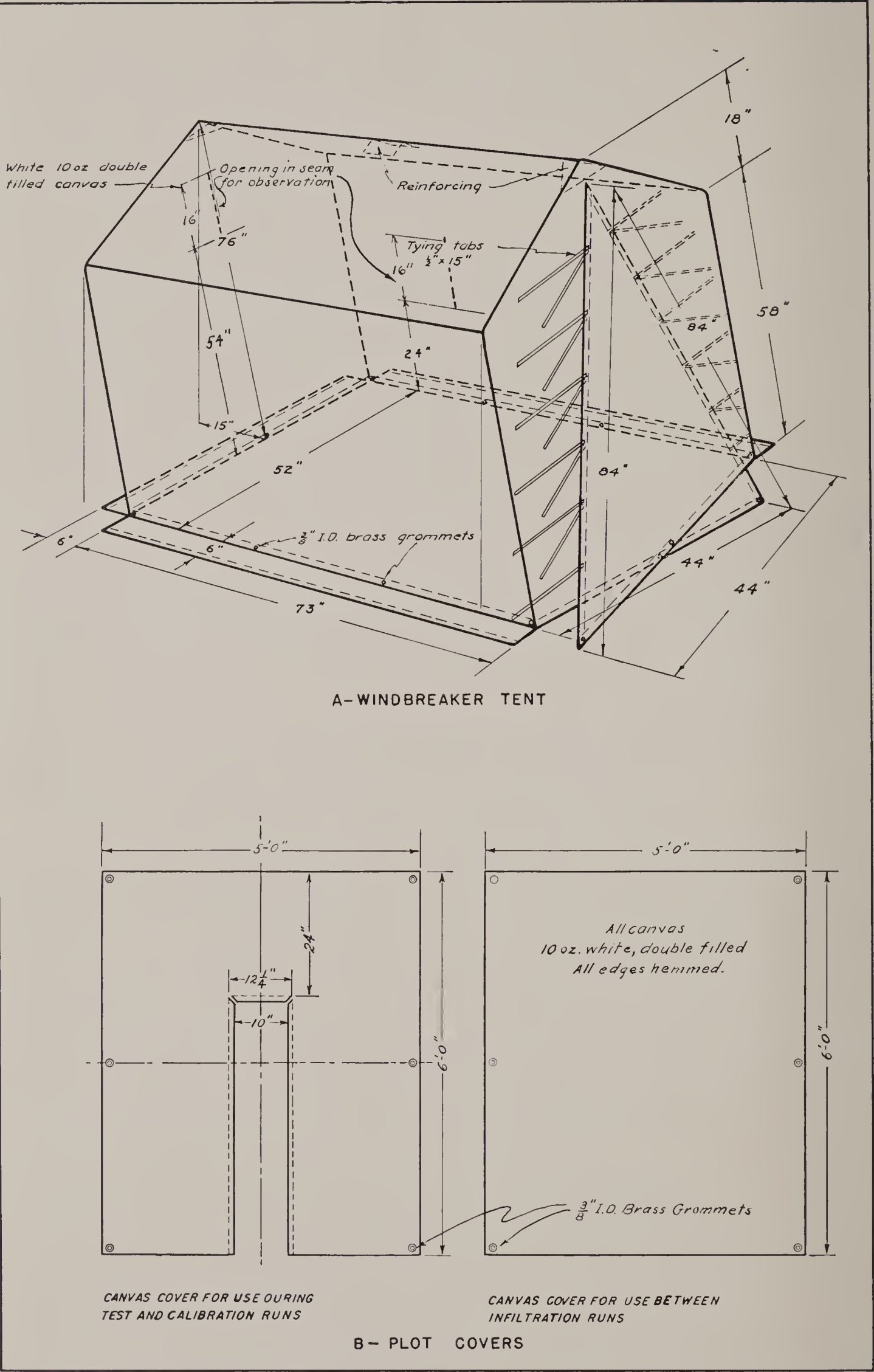


FIGURE 17.—A, windbreaker tent; B, plot covers.

SPECIFICATIONS FOR INFILTROMETER PLOT COVERS (FIGURE 17, B)

Purpose

For protecting border areas from wetting during calibration runs and for controlling evaporation losses between runs.

Equipment Per Plot

One slotted and one full cover constructed in accordance with figure 17, B.

Description

Slotted cover.—Five by 6 feet, 10-ounce double-filled canvas, fitted with six $\frac{3}{8}$ -inch brass grommets and slotted to fit around plots during calibration runs. All edges to be hemmed.

Full cover.—Five by 6 feet, 10-ounce double-filled canvas, fitted with six $\frac{3}{8}$ -inch brass grommets, and all edges hemmed.

Workmanship and Materials

To be of high quality, of uniform construction, and of finished appearance. Materials to be of best quality and free from defects. Allowable deviation in dimensions $\pm \frac{1}{2}$ inch.

Number Required

One slotted cover required with each infiltrometer, and one full cover required for each plot unit included in a sampling outfit.

Cost

Unit cost of either type of cover, approximately \$1.50.

SPECIFICATIONS FOR POINT GAGE

Purpose

To obtain rapid and accurate measurements of water elevations in small run-off collector tanks. The gage will be used outdoors under field conditions and therefore must be strongly built, highly resistant to deterioration through exposure to the elements, and capable of retaining a high degree of precision over a long period of use.

Equipment

One point gage.

Description

Type.—Gage to be constructed so that it can be rapidly and easily mounted in a vertical position in a 1-inch hole drilled in an iron support approximately $\frac{1}{4}$ -inch thick and held firmly in position by a knurled lock nut. The gage proper to consist of a graduated metal shaft capable of being moved past a fixed index mark and vernier and to be equipped with a rack and pinion mechanism to permit rapid and positive adjustment and accurate establishment of the final reading positions. The rack to extend the full range of the shaft. The shaft is to be provided with an adjustable point approximately 7 inches long. The point should be operated from the shaft in such a manner as to be in true center in relation to the vertical axis of the gage.

Range.—Gage to be capable of measuring through a range from 0 to 12 inches.

Graduations.—All graduations must be easily readable. Shaft to be graduated at intervals of 1/10 inch. Vernier to be graduated to allow direct readings to 1/100 inch. Shaft graduations to be numbered from 0 to 12, beginning at top, at intervals of 1 inch, with engraved or etched numerals. The opening in the vernier plate must permit the reading of the last significant numeral. For example, in a reading of 4.99 the numeral 4 on the scale must be visible.

Accuracy.—The gage to be capable of determining water elevations to within thirty-five ten-thousandths (0.0035) inch in any part or over the full range of the scale.

Workmanship and Materials

The best commercial practice should be followed in all machining and other operations. The gage must operate throughout its entire range without binding or slipping. Gage to be constructed throughout of rust-resistant material or to have all parts properly covered with such material. The shaft and vernier scales to be provided with a dull finish to prevent glare during readings. All material used to be of the best commercial quality and free from defects. Any part developing defects in material or workmanship within 1 year after date of purchase to be replaced without cost.

Number Required

One gage required with each infiltrometer.

Cost

Cost per gage, approximately \$17.

SPECIFICATIONS FOR PRESSURE-PUMP OUTFIT

Purpose

To supply a constant flow of water to the sprinkling system during infiltration runs.

Equipment

Pressure sprayer, consisting of one wheelbarrow frame, reservoir tank, water pump, pressure tank, and hose.

Description

Wheelbarrow frame.—Constructed of strong durable steel, equipped with a 16- to 20-inch wrought iron wheel and adequate supports for the reservoir and pressure tanks.

Reservoir tank.—Constructed of heavy galvanized iron or other rust-resistant material, 14- to 16-gallon capacity, and equipped with pump mountings capable of holding pump firmly in place during use.

Water pump.—Removable, hand-operated pump, constructed of brass or other rust-resistant material, easily operated without priming, capable of delivering a uniform flow of water at rates up to 95 gallons per hour at pumping speeds not in excess of 60 strikes per minute, and provided with pressure-hose connections to the pressure tank.

Pressure tank and hose.—Five- to 8-gallon high-pressure tank, galvanized both inside and outside¹¹. All seams to be welded and tested at 250 pounds pressure. Tank to be equipped with a connection for pump hose, a drain plug, a $\frac{1}{4}$ -inch male pipe fitting on top for pressure-gage connection, a $\frac{1}{4}$ - by $1\frac{1}{2}$ -inch male outlet pipe and an 8-foot length of best-grade high-pressure hose with both ends fitted with standard $\frac{1}{4}$ -inch female pipe connection.

Workmanship and Materials

The pump outfit to be of best commercial quality; any parts developing defects in material and workmanship within 6 months after purchase to be replaced without cost.

Number Required

One pump outfit required with each infiltrometer.

Cost

Total cost, approximately \$18.50.

SPECIFICATIONS FOR 0-60 PRESSURE GAGE

Purpose

To check pressures on pressure tank of pump outfit during runs.

Description

Zero to 60-pound pressure gage, graduated in pounds, $2\frac{1}{2}$ - to 3-inch face, bronze bushed movements or their equal, equipped with a brass petcock with standard $\frac{1}{4}$ -inch female pipe connections and constructed of rustproof material. Gage to be capable of measuring pressure within an accuracy of 1 pound over full range of scale, and sensitive to fluctuations in pressure of $\frac{1}{4}$ pound or less.

Workmanship and Materials

To be of good commercial quality and free from defects. Any part developing defects due to material or workmanship within 1 year after purchase to be replaced without cost.

Number Required and Cost

One gage required for each infiltrometer. Cost per gage, approximately \$1.50.

TOOLS AND ACCESSORIES NEEDED IN THE OPERATION OF THE INFILTRMETER

The assembling, installing, and operating of the infiltrometer equipment is greatly facilitated if a good set of tools is provided. This should include: one pair of standard 6-inch pliers, one pair 6-inch bent-nose pliers, one pair of side-cutting 7-inch pliers, one 8-inch screw-driver, one 10-inch adjustable crescent wrench, one 10-inch and one 12-inch pipe wrench, one claw hammer, one 10-inch spirit level, one 6-inch file, one hand ax, one crosscut hand saw, one spade, and one 3- or 4-pound hammer. Other accessories that will be needed are: two mason's 4-inch triangular trowels sharpened on the sides, one or two

¹¹ It is recommended that the pressure tank be galvanized after fabrication.

pairs of grass shears with offset handles, an Abney percent level, one 4-foot standard soil sampling tube with two extra cutters, 300 to 400 ointment cans 2 inches deep by 3 inches in diameter for soil samples, and one volume-weight soil sampler.

In addition, each party will need a station wagon, or some similar vehicle, for transporting the water and equipment and two 50-gallon drums, or similar containers, for transporting the water supply. The water containers should be thoroughly clean and provided with proper facilities for filling and draining. A garden-hose connection on the water tank and a 50- to 100-foot length hose has proved useful in getting the water from the truck to the plots.

When the infiltration sampling is to be done on areas not accessible by automobile, pack horses or other means of transporting the water and infiltration equipment will have to be provided. The methods used will be governed largely by local conditions and available facilities and can, therefore, be most efficiently worked out by the local field party responsible for the work.

MARKING PLOT WALLS TO SHOW THE CORRECT POSITIONS FOR THE RUN-OFF TROUGH AND COVER

Correct placement of the run-off trough and cover where the plots are on slopes is greatly simplified if the correct installing position for the various gradients to be sampled is engraved or otherwise indicated on the side wall of the plots, as shown in figure 18. Similar installation positions for the run-off trough cover should also be indicated on the edges of the rain pan. The accuracy of the permanent marking for use in the placement of the trough and cover depends, however, upon the accuracy with which the end cut-off wall is installed. If the cutting edge of the end wall does not coincide with the end of the side walls, the rain catchment area of the plot, as delimited by the cutting edges of the run-off trough cover and plot wall, will be in error. Likewise if the end cut-off wall is not installed in a vertical position, the length of the plot, as delimited by the run-off trough and end wall, will not be the same as the rain catchment length.

If the plot and rain pan walls are not marked to show the correct positions for installing the run-off trough and cover, a table similar to table 3 should be compiled, listing the slope distances necessary to insure a plot length of 30 inches, horizontal projection, for gradients between 0 to 100 percent.

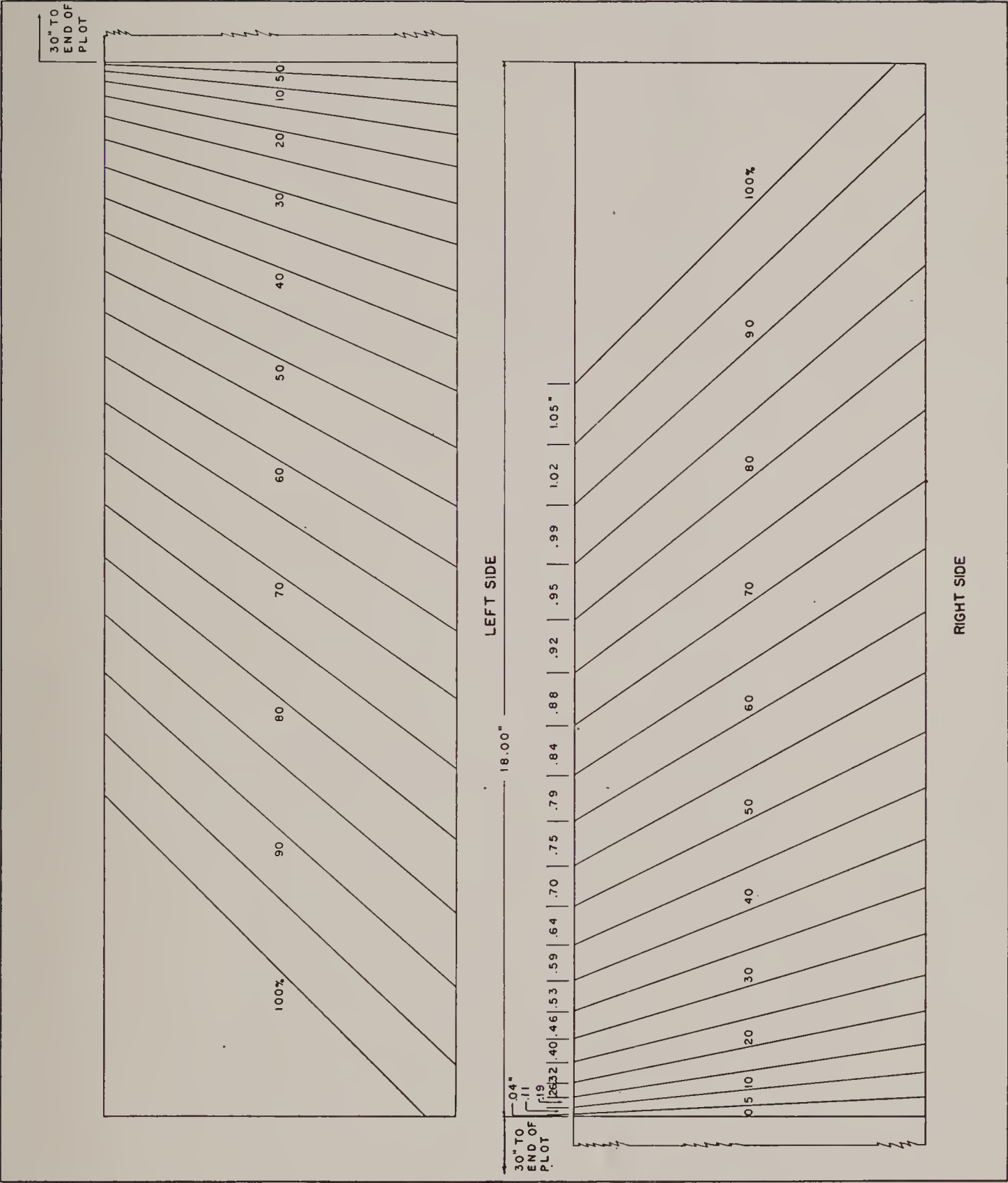


FIGURE 18.—Diagram for marking the plot walls to show the correct position for installing the run-off trough and cover when installations are made on slopes between 0 and 100 percent.

TABLE 3.—Slope distances for use in placing run-off trough and cover when installations are made on slopes between 0 and 100 percent.¹

| Slope | Slope distances | Slope | Slope distances |
|----------------|-----------------|----------------|-----------------|
| <i>Percent</i> | <i>Inches</i> | <i>Percent</i> | <i>Inches</i> |
| 0 | 30.00 | 20 | 30.60 |
| 1 | 30.00 | 25 | 30.92 |
| 2 | 30.01 | 30 | 31.32 |
| 3 | 30.01 | 35 | 31.78 |
| 4 | 30.02 | 40 | 32.31 |
| 5 | 30.04 | 45 | 32.90 |
| 6 | 30.05 | 50 | 33.54 |
| 7 | 30.07 | 60 | 34.99 |
| 8 | 30.10 | 70 | 36.62 |
| 9 | 30.12 | 80 | 38.42 |
| 10 | 30.15 | 90 | 40.36 |
| 15 | 30.34 | 100 | 42.43 |

¹If the plot walls are marked to show the correct positions for placing the run-off trough and cover on different slopes the above table of slope distances will not be required.

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